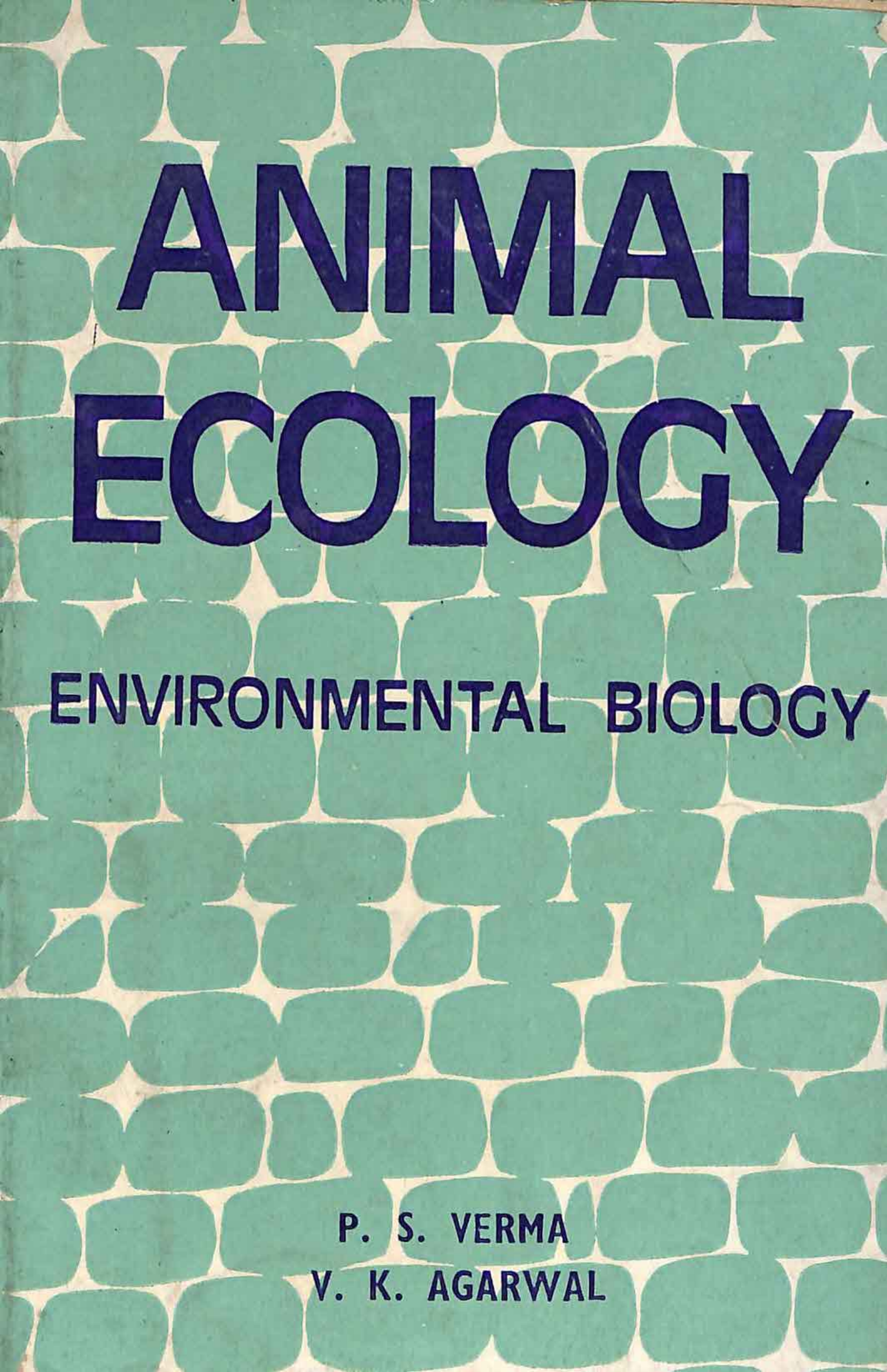

ANIMAL ECOLOGY

ENVIRONMENTAL BIOLOGY

P. S. VERMA
V. K. AGARWAL

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ANIMAL ECOLOGY

(ENVIRONMENTAL BIOLOGY)

(For B.Sc., B.Sc. (Hons.) and M.Sc. Classes of All Indian Universities)

By

P. S. VERMA
M. Sc., Ph.D., F.E.S.I., F.A.Z.

V. K. AGARWAL
M. Sc.

DEPARTMENT OF ZOOLOGY,
MEERUT COLLEGE, MEERUT

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Preface

In the recent years many Indian Universities have incorporated the subject of Ecology or Environmental Biology in the curricula of B. Sc., B.Sc. (Hons.) and M. Sc. classes. In fact Ecology or Environmental Biology is the single biological subject which has come forward to the rescue of modern man for solving his numerous newly-arose problems, such as soil erosion, and increasing desertification, recurring floods, ever shrinking natural resources, human population explosion, epidemics, gross pollution and resultant ailment of the human environment, to name a few. These problems, naturally, have cropped up due to growth of human culture and civilization, increased industrialization and development and thoughtless exploitation of the nature for various types of its resources. Ecology has provided the matching answer to many of these problems and future planning of development of India and other countries and becoming more and more ecologically oriented.

In the tune of such an ecological perspective, the authors have prepared this book of Ecology or Environmental Biology to provide the readers an introductory yet quite exhaustive and recent account of different topics of Ecology. They hope that this book will serve the purpose of readers more adequately.

Thanks are due to Sri Shyam Lal Gupta and Shri T.N. Goel of M/s. S. Chand and Company Ltd., New Delhi, for their whole hearted cooperation in the publication of this book. The authors are also thankful to Shri Ravi K. Gupta, B.E. (Mechanical), Production Manager for expediting the publication. Suggestions for further improvement of the book will be thankfully acknowledged and incorporated in the next edition.

Department of Zoology,
Meerut College, Meerut

P. S. VERMA
V. K. AGARWAL

CONTENTS

Chapters **Pages**

1. Introduction **3—16**

Definition of ecology ; historical background of ecology ; a preview of ecology ; branches of ecology ; relationship of ecology with other disciplines ; materials and methods in ecology ; significance of ecology for man.

2. Environment **17—52**

Atmosphere and air—physico-chemical structure of atmosphere ; lithosphere and soil—soil, soil formation of pedogenesis, process of soil formation, soil profile, morphology of soil, physical properties of soil, chemical properties of soil, classification of soils, major soil types of India, soil as habitats for animals, soil fauna and soil flora ; hydrosphere and water—physical properties of water, chemical properties of water, the hydrologic cycle, effect of factor of aquatic environment on aquatic organisms, aquatic flora and fauna ; snow as habitat.

3. Abiotic environmental factors **53—80**

Nature of response of organisms to abiotic environmental factors ; essential elements and limiting factors—the Liebig-Blackman law of limiting factors ; threshold and rate ; Shelford's law of toleration ; types of abiotic environmental factors—temperature, light and radiations, pressure, geomagnetism and gravity, mass movements in air and water, tide, chemical abiotic factors ; microclimate.

4. Biotic environmental factors **81—102**

Interspecific biotic factors—neutralism, competition, mutualism, protocooperation, commensalism, ammensalism, parasitism, predation ; intraspecific biotic factors—colonization, aggregation, social organization, psychological factors.

5. Animal population **103—118**

Population density ; natality of population ; mortality of population ; age distribution of population ; growth form of population ; growth rate of population ; population dispersion—emigration, immigration, migration ; regulation of population size ; population cycles.

6. Biotic communities **119—140**

Types of communities ; community structure—ecological niche ; species abundance and diversity of the community—community dominance ; trophic structure of the community ; community stability—correlation of environmental gradients and community gradients ; ecotone and edge effect ; communication between communities ; community stratification—vertical differentiation (stratification of community), horizontal stratification of community ; temporal

differentiation of community ; alteration of community patterns in time—ecological succession, community retrogression, community evolution.

7. **Ecosystems** 141—169

Components of the ecosystems—example of ecosystems, feed-back loop ; biogeochemical cycles—organic and abiotic phases of geochemical cycles, types of biogeochemical cycles—water cycle, gaseous cycles, sedimentary cycles ; energy flow in ecosystems—energy in an ecosystem ; ecological pyramids—types of ecological pyramids.

8. **Aquatic ecosystems : Fresh water communities** 170—190

Aquatic ecosystems—subdivision of aquatic ecosystems ; fresh water ecosystems—physico-chemical nature of fresh water ; lentic ecosystems, lakes and ponds ; biotic communities of lakes and ponds ; distribution of oxygen and dissolved nutrients in lakes ; lotic ecosystem—characteristic of lotic environment, rapidly flowing water, slowly flowing water.

9. **Aquatic ecosystems : Estuarine and marine communities** 191—211

Physico-chemical aspects of estuaries ; biotic communities of estuaries ; marine ecosystems ; physico-chemical aspects of marine environment ; marine communities—biotic communities of oceanic region, biotic communities of continental shelf ; coral reef a specialized oceanic ecosystem-biotic communities of coral reef.

0. **Terrestrial ecosystems** 212—228

Physico-chemical nature of terrestrial ecosystem and their comparison with aquatic ecosystems ; classification of terrestrial ecosystems—the biogeographic realms or regions, biomes—tundra biome, high altitude or the alpine biome, forest biomes, tropical savanna biomes, grassland biomes; desert biomes.

ECOLOGY
(Environmental Biology)

CHAPTER 1

INTRODUCTION

No micro-organism, plant or animal species including man is an isloated organism living in a void. Each of them is surrounded by a host of physical conditions that can be measured in terms of chemical composition, texture, pressure, temperature, and humidity, as well as being surrounded by a host of other living organisms which can be described in such terms as plants, animals, food, parasites, and enemies. Studies of the inter-relationships of organisms with their physical and biotic environments are termed **environmental biology** or **ecology**. These words are very much in the public consciousness today as we become aware of some of past and current ecologic malpractices. It is important for everyone to know and appreciate the principles of this aspect of biology so that he can form an intelligent opinion regarding topics such as insecticides, detergents, mercury pollution, sewage disposal, power dams, urbanization and their effects on mankind, on human civilzation, and on the world we live in.

The term **ecology** *(oekologie)* is derived from two Greek words-*oikos*-means 'house' or 'place to live' and—*logos* means 'a discussion or study'. Literally, ecology is the study of organisms 'at home', in their native environment. The term first of all introduced by **Reiter** in 1868, but because the German biologist **Ernst Haeckel** first of all fully defined this term and he made an extensive use of this term in his writings, therefore, usually he is falsly credited for the coinage of the term ecology (see **C. B. Knight**, 1965).

DEFINITION OF ECOLOGY

The traditional definition of ecology is '*the study of an organism and its environment*', however, different ecologists have defined it variously. **Ernst Haeckel** (1869) defined ecology as, *the total relation of the animal to both its organic and its inorganic environment.*' **Charles Elton** (1927) in his pioneering book *Animal Ecology* defined ecology as '*scientific natural history*'. Although this definition does point out the origin of many of our ecological problems, yet it is much broad and vague like Haeckelian definition of ecology. In 1936, **Taylor** defined ecology as "*the science of all the relations* *of all organisms to all their environments.'* **Allee** *et. al.* (1949), in their definition of ecology, clearly emphasizes the all-encompassing character of this field of study. According to them—"*Ecology may be defined broadly as the science of the interrelation between living organisms and their environment, including both the physical and biotic environments, and emphasizing interspecies as well as intraspecies relations.*" Though, **F. J. Vernberg** and **W. B. Vernberg** (1970) are completely agreed with Allee *et. al's* definition, yet there are certain ecologists which are not satisfied with this definition and have provided their own definitions of ecology. For instance, **Andrewartha** (1961) defined ecology as '*the scientific study of the distribution and abundance of organisms*'. **G. A. Petrides** (1968) has defined ecology as '*the study of environmental interactions which control the welfare of living things, regulating their distribution, abundence production and evolution.*" **Eugene Odum** (1963, 1970) has defined ecology as the "*structure and function of nature.*" **C. J. Krebs** (1972) has shown his satisfaction over the definition of Odum for its emphasizing the form and function idea that permeates biology, but, he considered it vague. He, however, proposed the modified version of **Andrewartha's** definition of ecology, according to which "*ecology is the scientific study of the interactions that determine the distribution and abundance of organisms*". According to **M. E. Clark** (1973) "*Ecology, the science of the environment, is a study of ecosystems, or the totality of the reciprocal interactions between living organisms and their physical surroundings*". Two Indian authors **Ananthakrishnan and Viswanathan** (1976) have defined ecology as '*the study of the ways by which individual organisms, populations of species and communities of populations respond to diverse environmental pressures, i.e., physical and biotic pressures.*' This definition merely is the modified version of the definition of ecology which has been originally proposed by **T. Lewis** and **L. R. Taylor** (1967) in their book, *Introduction to Experimental Ecology*. According to Lewis and Taylor '*Ecology is the study of the way in which individual organisms, populations of same species and communities of populations respond to these changes.*' Lastly to avoid this ecological jargon we can rely upon the simple definition of ecology which has been provided by *Chamber's Twentieth Century Dictionary* (1972). According to it, *ecology is the study of plants or of animals, or of peoples and institutions, in relation to environment.*

HISTORICAL BACKGROUND OF ECOLOGY

The roots of ecology lie in natural history, which is as old as man himself. The vague beginning of ecology may be traced back to prehistoric man, who utilized environmental information to hunt food, fishing, trap animals, find edible vegetation, and locate shelter to survive the hardships imposed by nature. An increased knowledge of the importance of environmental conditions led quite naturally to religious rituals, worship of weather gods, and rain dances, all of which are quite prevalent in different social groups and tribes of Indian civilization. The establishment of agriculture increased the need to learn about the practical ecology of plants and domestic animals.

1. ECOLOGY IN INDIAN CLASSICS

Early Indian philosophers and thinkers had some knowledge of ecology as has been revealed by the Indian classical writings, in the Vedic, Upanishadic, Pauranic, and Epic literature. **Charaka** considered the important factors of *Vayu* (air and gases), *Jala* (water), *Desha* (topography) and *time* in regulating the life of plants (see **R. Misra**, 1962). The great classical Indian Poet **Kalidasa** has displayed his ecological faculty in his classics—'*Meghdoot*' and '*Abhigyan Sakuntlam*'.

2. EARLY GREEK'S IDEAS OF ECOLOGY

The early Greek philosophers too were well aware of the importance of environmental studies. One of the paper entitled on *Airs, waters and places* of **Hippocrates** stressed on the need of ecological background for medical students. According to him—"whoever wished to investigate medicine properly, should proceed thus : in the first place to consider the seasons of the year, and what effects each of them produces……" In the fourth century B. C. **Aristotle** made references about the habits of animals and environmental conditions prevailing in certain areas, in his writings on natural history. One of the Aristotle's student, **Theoprastus** (370–250 B. C.) who is regarded as the first true ecologist, wrote about the association of plant communities and the relation of plants to each other and the non-living environment,

3. ECOLOGY IN 18TH CENTURY

After a considerable long gap of many centuries, the first naturalist who made a serious attempt to systematise knowledge concerning relations of animals to environment was **Buffon** (1707–1788). Though such works as *Historia animalium* by **Konard Gesner** (1516–1565); 14 volumes of collected works of natural history by **Ulisse Aldrovandi** (1522–1605); the natural histories of fishes and birds by **Pierre Belon** (1517–1564). *The plants* by **Andrea Caesalpino** (1519–1603), the botanical work for **Gaspard Bauhin** (1550–1624); demographical studies about human ecology by **Graunt** (1664): studies of the sexuality of plants by **Rudolph Camerarius** (1665–1721), the works of English naturalist **John Ray** (1627–1705), studies on natural history of insects by French naturalist **Rene Reaumur** (1683–1757) and the works of many other naturalist doubtlessly laid the foundation upon which **Buffon** built his remarkable work. **Buffon** considered that animals and plants developed adaptations which enabled them to favourably respond to their environment and termed this **environmental induction**. He touched on many of our modern ecological problems and recognised that populations of man, other animals and plants are subjected to the same processes. Buffon also explained how the great fertility of every species was counterbalanced by innumerable agents of destruction. He thus dealt with problems of population regulation.

Malthus published one of the earliest controversial books on demography. In his *Essay on Population* (1798) he calculated that although the numbers of organisms can increase geometrically (1, 2, 4, 8, 16, 32......); their food supply may never increase faster than arithmetically (1, 2, 3, 4, 5......). Such a great disproportion between these two powers of increase led **Malthus** to infer that reproduction must eventually be checked by food production. Many workers questioned the ideas of **Malthus.** For example, in 1841 **Doubleday** brought out his true law of population. To contradict the **Malthus** idea, he believed that whenever a species was threatened, nature made a corresponding effort to preserve it by increasing the fertility of its members. Human populations that were undernourished had the highest fertility; those that were well fed had the lowest fertility. **Doubleday** explained these effects by the oversupply of mineral nutrients in well-fed populations.

4. ECOLOGY IN 19TH CENTURY

In 1807 **Humbolt** after extensive travels of tropical and temperate South America, discussed the geographical distribution of plants and animals in relation to climate. **Saint-Hilaire** (1859) used the term "**ethology**" for the study of relations of organisms to environment and outlined a volume, which he never wrote, on instincts, habits, and other ecological matters. The term ethology, though was not accepted by early ecologists, but this term is now used as an important ecological discipline dealing with animal behaviour. In 1869 **Haeckel** proposed "**oecologie**" for the relations of organisms to organic and inorganic environments. The modern term *ecology* is derived from the word oecologie. The observations of **Priestley** and **Scheele** that plants produce oxygen led to an understanding of the inter-relationships of plants and animals. The discovery that green plants and animals use carbon dioxide and water to form organic matter for use by animals and resulting in the release of oxygen and water as wastes, provided new understanding of ecological food chains. **Justus Von Liebig** (1803–1873) initiated the idea of carbon and nitrogen cycles in nature. **Louis Agassiz** (1807–1873) initiated the research in marine ecology by establishing many laboratories for marine ecological research. **C. Mobius** (1877) introduced the word **"biocoenosis"** to designate a group of organisms as an ecological unit. **Charles Darwin** (1809—1882) and **Alfred R. Wallace** (1823—1915) have increased our knowledge of island or insular life with their characteristically different types of environmental conditions. **Hensen** (1887) made excellent quantitative studies of plankton. **S. A. Forbes** (1887), in a classical paper on "*The Lake as a Microcosm*" suggested that the species assemblage in a lake was an organic complex and that by affecting one species we exerted some influence on the whole assemblage. Thus each species maintains a 'community of interest' with the other species, and we cannot limit our studies to a single species. **Forbes** believed that there was a steady balance of nature, which held each species within limits year after year, even though each species was always trying to increase its numbers.

Schroter (1896) introduced the terms **"autecology"** and **"synecology"**. **Herdman** (1896) indicated the economic possibilities of scientific agriculture. Danish botanist **Warming** (1895, 1909) raised questions about the structure of plant communities and the associations of species in these communities. In 1899 **H. C. Cowles** described *plant succession* on the sand dumes at the Southern end of Lake Michigan.

5. ECOLOGY IN THE 20TH CENTURY

At the beginning of the twentieth century ecology was a young, but an established science and such eminent ecologists as **Wasmann** (1901), **Dahl** (1901) and **Wheeler** (1902) were discussing whether Saint Hilaire's ethology or Haeckel's ecology should be used to designate the science of relations of organisms to environments. The latter term has gradually come into general usage. **Case** (1905) discussed environmental conditions of past geological periods and has continued to make contributions in that field. Two botanists, **Clements,** in his "*Research Methods in Ecology*" (1905) and subsequent writings, and **Warming** in his "*Oecology of plants*". (1909, 1925) have done much to clarify ideas and contribute terms. **Adams** (1913) gave an excellent review of significant ecological literature, urged the usefulness of ecological surveys, and discussed methods to be used in making them. **Shelford** (1912) demonstrated excellent examples of ecological succession and has made notable contributions concerning animal communities (1913) and environmental factors (1929). One of the interesting aspects of development of ecology during the first third of this century remains that a tendency toward increased specialization in ecology has occurred as is evidenced by the establishment of such disciplines as **palaeoecology**, a study of environmental conditions and life as it existed in past ages. Pollen analysis, radioactive dating, and palaeontology have aided the palaeoecologists. Other specialized fields of ecology which took their birth during this time, are **zoogeography**, the scientific study of the geographic distribution of animals ; **oceanography**, the study of the biotic and physical conditions existing on oceans, bays, and estuaries, and **limnology**, the study of the living and non-living components of inland waters. With the establishment of specialized disciplines of ecology, the value of application of ecology to such fields as agriculture, forestry, wildlife conservation, fisheries management, and pest control became apparent, and thus a new descipline called **applied ecology** came into its existence.

In the second decade of 20th century great emphasis was laid on statistical studies on populations, sampling techniques, and community studies. During this period several important texts published—**Lotka's** *Elements of Physical Biology ;* **Elton's** *Animal Ecology ;* **Volterra's** *Animal Ecology* ; **Gause's** *The Struggle for Existence*, and **Bodenheimer's** *Problems of Animal Ecology*. Certain distinguished ecologists of earlier half and present decade of this century are **Clements, Cowles, Shelford, Pearse, Oosting, A. M. Woodbury, Hutchinson, Deevey, Lindeman, F. E. Smith, Slobodkin, Hairston, T. Park, O. Park, Emerson, MacArthur, G. L. Clark, C. B. Knight, Odum, R. L. Smith, F. J. Vernberg, C. J. Krebs, R. Misra, M. S. Mani**, etc.

Development of ecology during this century have been greatly stimulated by organization of ecologists. The British Ecological Society was founded in 1913 and this society sponsored two Journals namely *Journal of Ecology* (started in 1913) and *Journal of Animal Ecology* (started in 1932). Following the British, the Ecological Society of America was established in 1915 which also sponsored two publications, *Ecology* in 1920 and *Ecological Monographs* in 1931.

Currently, papers of ecological nature appear in a variety of Journals, reviews, monographs, periodicals and magazines, certain important of which are following—*Science, Nature, Evolution, Bioscience, Endeavour, Journal of Soil and Water Conservation, Advance*

Ecological Research, Archivio di Oceanographia Limnologia, Proceedings of Ecological Society Australia, Biological Bulletin, Journal of Experimental Botany, Journal of Experimental Zoology, Biological Review, Geographical Review, Journal of Wildlife Management, Quaternary Biological Review, Turtox News, Marine Biology, J. Parasitology, and Scientific American. A variety of Indian Journals also publish papers of ecological significance ; some of them are following : *Hydrobiologia, Journal of Marine Biol. Ass. India, Andhra University Mems. Oceanography, Journal of Madras University, Bulletin of Madras Government Museum, Indian Journal of Fisheries, Indian Journal of Entomology, Indian Journal of Agriculture Science, Proceedings of Indian Academy of Science, Records of Zoological Survey f India and Tropical Ecology.*

A PREVIEW OF ECOLOGY

The ecology is the study of ecosystems or the totality of the ciprocal interactions between living organisms and their environents. The term **organism** refers to a dynamic biological unit which greatly influenced by an enveloping and fluctuating environment. r a given organism, the environment consists of all the surrounding ysical and biological factors with which it interacts. **Maelzer** (65) suggests that **environment** should be defined as the sum total everything that directly influences the animal's chances to survive a reproduce. The intimately local and immediate surrounding of tl organism is called **microenvironment,** while, the **macroenvironnt** is the sum total of the physical and the biotic conditions existi external to the organism and its microenvironment. The total lisupporting environment remain restricted to a thin surface zone arnd our planet earth. This restricted life-supporting zone of earth is lled the **biosphere**. The biosphere too is not entirely hospitable to fe ; in one region called **parabiosphere,** severe environmental coitions permit inhabitation by some organisms only in the resistantages of their life cycle. The parabiosphere includes broad areas sucas the higher altitudes and a greater part of the cold polar regns, as well as numerous localized regions such as volcanos, geyss, and grossly polluted areas. The region of the biosphere in whic active metabolic processes of organisms are possible is called the **biosphere**. Fear has been expressed by many modern ecologists that e parabiosphere is increasing in size at the expense of the eubiophere, owing to the destructive activities of man.

Further, the biosphere includes four major environmental categorie cr **habitats—marine, brackish, fresh water,** and **terrestrial habjats.** Each of these habitats may be further subdivided into smaller categories. For example, a fresh water environment may be large lake, a pond, a river, or a stream. Likewise, terrestrial environment may include following sub-categories, all of which are called **biomes**—tundra, coniferous forest, deciduous forest, broad-leaved ever green subtropical forest, grassland, desert, chaparral and tropical rain forest. Each of the subtype of the four habitats has a typical set of physical and biological features and each forms a **ecological complex ecosystem**. The ecosystem is a natural unit or a subunit of biosphere which composed of **non-living, physical** or **abiotic** and **living, biological** or **biotic components** whose interactions result in a stable self-prepetuating system.

Among the main physical (abiotic) components of an ecosytem are such **climatic factors** as solar radiation, temperature, rainfall, and such **physical factors** as light, pressure, geomagnetism, and such **chemical factors** as acidity, salinity and the availability of inorganic nutrients needed by plants. The biological (biotic) factors in an ecosystem are the totality of all living organisms and their organic by-products. This include not only the larger plants and animals tha are readily observed, but all the microscopic organisms as wel bacteria in the soil or sediments, in the digestive tracts of animal or infecting plants and animals ; plankton that live in water ; viruse that cause disease ; fungi that live in the soil or on decaying o ganisms ; mites that feed on bacteria, and fungi and so on.

Each kind of living organism found in an ecosystem is called **species**. A species comprises of all those organisms which are sufficierly alike genetically so as to make them distinguishable from all othr types of organisms. Within an ecosystem, there usually exists a w e variety of species, all of which interact directly or indirectly w h each other.

All individuals belonging to a particular species in a given eosystem form a **population**. We thus speak of the population of d-legged frogs in a pond, of the population of herring in the North ea or of the population of the blue-green alga in a eutrophied lake. he size of a population of any given species is determined by a bal ce between its **reproductive potential** and the **environmental resista ce.** Further, within an ecosystem there is a great number of popula ons of different species, all interacting with one another as a **comm ity** and with the physical environment as well. A community, thu can be defined as an assemblage of populations inhabiting an area p sessing some uniformity in physical feature and vegetation. W le a population is formed of a number of animals and plants inhabting an area, a community is an aggregate of several species of plant and animal population—the **biotic community** which forms a distinct ecological unit. A biotic community, thus, is a naturally occurring assemblage of plants and animals, living in the same environment, mutually sustaining and interdepending, constantly fixing, utilizing and dissipating energy. The place that an organism occupies in a biotic community which expresses its functional status, is called the **'niche'**. The niche may be defined as the place that an animal occupies in a biotic community in relation to its food and enemies. Lastly, all biotic communities exhibit some form of layering or **stratification**, which largely reflects the life forms of the plants and which influences the nature and distribution of animal life in the community.

The structure of an ecosystem ultimately depends upon the photosynthetic plants (called **primary producers**) which support it. These primary producers utilize energy of solar radiation for synthesis of organic molecules from carbon dioxide, water and nutrient minerals. Part of the energy absorbed by plants is used for their own maintenance, the rest going into the synthesis of plant tissues or **biomass**. Plant biomass serves as food for **herbivorous** animals feeding on plants. Herbivorous are thus the **primary consumers**. They in turn become food for **carnivores**, who are **secondary consumers**. Each of these steps in the transfer of the original plant biomass through an ecosystem is known as **trophic**, or feeding level. This type of feeding sequence forms a **food chain**, or more accurately **food web**, since omnivorous species, such as man, may feed upon anything from plants to top level carnivores. The last category of the food web is formed by **decomposers**. Plant lose leaves or die, animals excrete wastes and, on dying, become carcasses. Eventually all these dead materials, if not eaten by **scavengers**, are decomposed, their organic matter being converted back into organic nutrients. The major decomposers are bacteria and fungi living in sediments or soil where organic debris accumulates.

The study of a food-web reveals the fact that basic elements of living systems, carbon, oxygen, nitrogen, phosphorus, and so forth, are originally obtained in the form of minerals (CO_2, H_2O, NO_3^-, $PO_4^{\equiv}$) by plants. They then pass from one trophic level to the next in the form of organic molecules. Eventually the decomposers return them, as mineral nutrients, to the air, water and soil, to be used again by plants. Mineral nutrients are thus **recycled** over and over again within an ecosystem. Further, the original source of energy for the entire ecosystem is the sun. A fraction of this solar energy, initially captured during photosynthesis, is dissipated at each trophic level as waste metabolic heat. Thus, in any ecosystem energy is utilized only once.

Lastly, occasionally natural or man-made cataclysms (*e.g.*, fire, floods and avalanches are the natural cataclysms, while, man-made cataclysms include the bulldozing of the landscape, abandoning of unproductive fields or creation of a new lake behind a dam) occur which destroy a stable ecosystem, and a new one gradually takes its place. In such cases one can observe a sequence of biotic stages as a new ecosystem develops on an initially barren site. This is known as **ecological succession**. During chronological ecological succession, early colonists are often replaced, and **species diversity** increase until eventually a stable community is achieved. It is hypothesized but not yet proved, that species diversity leads to community stability in a self-reinforcing manner.

BRANCHES OF ECOLOGY

Ecological studies may deal with the study of the individual organism or an individual species in relation to their habitat (**autecology**) or the study of groups of organisms which are associated together as unit—the biotic community in relation to a particular area or biotope or habitat (**synecology**). **Demecology** is that branch of ecology which deals with the ecology of populations. Early ecologists have recognized two major subdivisions of ecology in relation to plants and animals—**plant ecology** and **animal ecology**. But when it was found that in the ecosystems plants and animals are very closely associated and interrelated, then, both of these major subdivisions of ecology into plant ecology and animal ecology became vague. Besides these major subdivisions the ecology has been classified in the following branches according to the level of organization, kind of environment or habitats and taxonomic position :

1. **Habitat Ecology** : It deals with the study of different habitats of the biosphere. According to the kind of habitat, ecology is subdivided into **Marine Ecology**, **Freshwater Ecology**, and **Terrestrial Ecology**. The terrestrial ecology too is further subdivided into **Forest Ecology**, **Cropland Ecology**, **Grassland Ecology**, *etc.*, according to the kind of study of its different biomes.

2. **Ecosystem Ecology** : It deals with the analysis of ecosystem for structural and functional point of view including the interrelationship of physical (abiotic) and biological (biotic) compo-rents of environment.

3. **Conservation Ecology** : It deals with methods of proper management of natural resources like land, water forests, sea, mines, etc., for the benefit of human beings.

4. Production Ecology : It is the modern subdivision of ecology which deals with the gross and net production of different ecosystems like freshwater, sea water, agriculture, horticulture, etc., and tries to do proper management of these ecosystems so that maximum yield can be get from them.

5. Radiation Ecology : It deals with the study of gross effects of radiations and radioactive substances over the environment and living organisms.

6. Taxonomic Ecology : It is concerned with the ecology of different taxonomic groups and eventually includes following subdivisions of ecology—**plant ecology, insect ecology, invertebrate ecology, vertebrate ecology, microbial ecology** and so on.

7. Human Ecology : It deals with the study of man with his environment.

8. Space Ecology : It is modern subdivision of ecology which remains concerned with the development of partially or completely regenerating ecosystems for supporting life of man during long space flights or during extended exploration of extra-terrestrial environments.

Thus, the roots of ecology lie in natural history, human demography, biometry, and applied problems of agriculture, horticulture and medicine.

RELATIONSHIP OF ECOLOGY WITH OTHER DISCIPLINES

Modern ecology is a multidisciplinary science which depends on a variety of disciplines like **physics, chemistry, mathematics, statistics, meterology, climatology, geology, geography, economics, sociology, agriculture science, forestry, horticulture, genetics, physiology,** etc. All these disciplines have helped in the better understanding of many ecological principles.

For instance, meterological and climatological data for certain geographic localities allow for a more subtle interpretation of results. A basic knowledge of forestry can be invaluable for a forest-ecologist to understand forest type distribution, floristic composition and prevalent environmental factors. Likewise, statistical data helps in interpreting the reasons for activity, population increases, migrations, probability of ecological events occurring in a particular area, sampling techniques and reliability of results. Palaeontology (geology) provides information about the ancestral organisms and environmental situations prevalent in past. Evolution and genetics are utilized to interpret the reason for organic changes when linked with environmental conditions, establishment of new populations and species, environmental effects on genetic populations and so on. Such interdisciplinary approaches to ecology, consequently have given rise to following sub-divisions of ecology.

1. **Ecological genetics** : An ecologist recognised a kind of genetic plasticity in the case of every organism. In any environment only those organisms that are favoured by the environment survive. The branch of ecology dealing with genetics in relation to ecology is called ecological genetics.

2. **Palaeoecology** : It deals with the movements of biotic elements based on palaentological evidence, which provides information about ancestral organisms and environmental conditions existing in the past.

3. **Ecophysiology** : The factors of environment have a direct bearing on the functional aspects of organisms. The ecophysiology deals with the survival of populations as a result of functional adjustments of organisms with different ecological conditions of the ecosystems.

4. **Chemical ecology** : It deals with the adaptations of animals or preferences of particular organisms like insects to particular chemical substances.

5. **Pedology** : It is a branch of terrestrial ecology and it deals with the study of soils, in particular their acidity, alkalinity, humus content, mineral contents, soil type, etc., and their influence on the organisms.

6 **Ecogeography** : It deals with the study of the role of the environment in animal distribution. It is related with **biogeography** which is concerned with the structural and functional relations of living organisms in space, which form the immediate environment of the individuals as well as populations. **Ecofloras** and **ecofaunas** are the lowest units of which a biogeographhic flora or fauna is made up of.

7. **Ecological energetics** : It deals with energy conservation and its flow in the organisms within the ecosystem. In it thermodynamics has its significant contribution.

Because of its far-flung involvements with so many fields ecology, is often regarded as a generality rather than a speciality. Visualizing this fact, an ecologist, **A. Macfadyen** (1957) wrote in his book *Animial Ecology: Aims and Methods—The ecologist is something of a chartered libertine. He roams at will over the legitimate preserves of the plant and animal biologist, the taxonomist, the physiologist, the behaviourist, the meterologist, the geologist, the physicist, the chemist, and even the sociologist; he poaches from* *all these and from other established and respected disciplines. It is indeed a major problem for the ecologist in his own interest, to set bounds to his divagations.*

MATERIALS AND METHODS IN ECOLOGY

Ecology has been attacked on three broad fronts the **mathematical**, the **laboratory**, and the **field**. These three approaches are interrelated, but some problems have arisen when the results of one approach fail to verify those of another. In current ecological investigations several advanced technological methods are employed to deal quantitatively with large complex systems such as the ecosystem. Tracer methodology, mass chemistry (spectrometry, colorimetry, chromatography, etc.), remote sensing, automatic monitoring, mathematical modeling and computer technology are providing the tools for such ecological analysis. However, most ecologist study ecology from either a **descriptive** or **functional** point of view. The descriptive point of view is mainly natural history and proceeds by describing the vegetation groups of the world, such as temperate deciduous forests, tropical rain forests, grassland and tundra, and by describing the animals, plants and micro-organisms and their inter-relationships for each of these ecosystems. The functional point of view on the other hand, is oriented more toward **relationships** and seeks to analyze general problems common to most or all of the different areas.

SIGNIFICANCE OF ECOLOGY FOR MAN

Man is himself an organism within an environment. Like other animals man is influenced by the physical features of his environment, he is absolutely dependent upon other species for his food, clothing, medicine, and other similar aspects and he has to adjust to other individuals of his own species. Therefore, the basic laws of ecology apply well to him and the fundamental knowledge is **must** for man for his own existence on this planet (Earth).

Man almost always has a modifying influence, and without proper regulation he often has a destructive effect. For instance, by applying certain ecological principles to such fields as agriculture, biological surveys, game management, pest control, forestry, horticulture, and fishery biology, he has received tremendous economic gains. Its knowledge is found critically important for intelligent conservation whether in relation to soil, forest, wildlife, water supply or fishery resources. Further, though man has been known to control his environment successfully to meet his needs, but indiscriminate control of different pathogens or pests such as bacteria, fungi, weeds, insects, rodents, etc., through use of different chemical-poisons or pesticides (bacteriocides, fungicides, insecticides, etc.), the release of massive quantities of radioactive debris, discarded chemicals and industrial waste into rivers result in atmospheric and aquatic pollution, which may have short and long term ecological effects. Further, rapid growth of urbanization and fast rate of multiplication of human population have resulted in fatal threat of scarcity of wild life, food, open space, and of survival.

There are certain other ecological problems. Agriculture and now forestry are concentrating upon monoculture—**single species ecosystems**—in spite of the difficulties and dangers attendant on unnaturally simplified ecosystems that lack a diversity of species. Over much of the world, especially in the grasslands, we continue to disrupt the energy balance through overgrazing and end up with eroded mountain sides, silt-clogged streams and lakes, and a scarcity of water. Therefore, future of human life on earth demands more knowledge about the ecosystems and other ecological problems.

CHAPTER 2

ENVIRONMENT

Each and every living organism has its specific surrounding, medium or environment to which it continuously interacts and remains fully adapted. The **environment** is the sum total of physical and biotic conditions influencing the responses of the organisms (**S.C. Kendeigh**, 1974). The life supporting environment of planet earth—the **biosphere** is composed of following three chief media—**air, soil** and **water,** which are the components of three major sub-divisions of the biosphere—**atmosphere, lithosphere** and **hydrosphere**, respectively. These media are not completely isolated from each other, however, some of the atmospheric gases are dissolved in all natural waters, and some moisture is persent almost everywhere in the atmosphere. Each of these media and their subsequent major subdivisions of biophere can be discussed separately in following manner :

A. ATMOSPHERE AND AIR

The multilayered gaseous envelope surrounding the planet earth is called **atmosphere**. The atmosphere remains in contact with all the major types of environment of earth, interacting with them and greatly affecting their ability to support life. It filters sunlight reaching the earth, affect climate, and is a reservoir of several elements essential for life.

PHYSICO-CHEMICAL STRUCTURE OF ATMOSPHERE

According to **R. L. Smith** (1974) the atmosphere surrounding the earth consists of a series of following layers—exosphere, heterosphere, mesosphere, stratosphere and troposphere.

1. **Exosphere**—The exosphere is the outer fringe of earth's atmosphere which extends some 20,000 miles from the planet. Its dominant element is hydrogen and its temperature ranges from 200° to 10,000°F. In this region the atoms and particles are so far apart that rarely collide and friction is negligible. Its high temperature is caused by solar energy (radiant energy of sun). The lower part of exosphere contains abundance of helium besides hydrogen and is called **helium zone**.

2. **Heterosphere**—The exosphere is followed by **ionosphere** and **thermosphere** of **heterosphere**. In heterosphere oxygen and nitric

oxide occur in a ionized state and their ionization is caused by ultraviolet radiation. The outer reach of ionosphere (zone of ionized air) is 250 miles from earth. Its temperature is 200°F and its upper limits are characterized by a layer of oxygen largely ionized into ozone byultraviolet radiation. The lower sub region of heterosphere is called **thermosphere**. It is 125 miles out from the earth and contains mixture of nitrogen and oxygen in the ratio of 1 : 1. In thermosphere molecules of air are so widely spaced that high frequency audible sounds are not carried by the atmosphere. Further, in it the temperature decreases as the distance from the sun increases.

3. **Mesosphere**—The mesosphere is that layer of air which is within 55 miles of the earth's surface. This is a region of cold temperature (—120°F). The temperature of mesosphere, however, is gradually increases as mesosphere leads to stratosphere.

4. **Stratosphere**—The stratosphere is 30 miles away from the earth, having a fairly constant temperature at —75°F to —45°F in its outer reaches which increases upto 30°F at its lower boundary. Within the stratosphere, ozone (O_3) accumulates sufficiently to produce a well marked ozone layer called **ozonesphere**, which extends from about 13 to 23 miles above the sea level. In ozonesphere, the sunlight ionizes oxygen to ozone by photochemical dissociation. The ozonosphere completely absorbs solar radiation, ultraviolet radiation from the sun and also a lot of the solar infra-red thus becoming warmer than adjacent layers above or below. The amount of ozone present varies from time to time, probably with season and with solar activity, but because of its extra heat, it acts like a blanket that reduces the cooling rate of the earth and thus adds to the effect of water vapour.

5. **Troposphere** : The lowest region of atmosphere which hangs at 5 miles over the earth at the poles, nearly 10 miles over the earth at the equator, and which subjects to differential heating, temperature inversions and convertion currents is called **troposphere**. In it temperature drops rapidly from 30° to —70°F. Troposphere is the layer of sulphates and is the region of strong air movements and cloud formation, *i.e.*, it is the locus of most weather phenomena. Man along with other living organisms live in troposphere.

THE AIR

The gaseous mixture of troposphere, is utilized by most organisms in respiration to liberate energy from food during oxidation and is called **air**. The air has a relatively constant composition of gases, as has been shown in following table :

Table : Composition of atmospheric air.

Component	% by volume	%by weight.
Nitrogen (N_2)	78.09	75.54
Oxygen (O_2)	20.93	23.14
Argon (A)	0.93	1.27
Carbon dioxide (CO_2)	0.03	0.03
Miscellaneous	0.02	0.02

Miscellaneous item includes traces of hydrogen, ozone, radon, helium, neon, krypton, xenon, sulphur dioxide, hydrogen sulphide, ammonia, methane, etc. Besides these gases, air may carry suspensions of liquids such as water in clouds and solids such as dust from the ground (soil), smoke from fires or salt from ocean spray.

In general, the composition of these gases in air in other media on earth, such as water or soil, is in equilibrium with the atmosphere. In special ecological habitats such as the anaerobic regions of deep lakes or sand-mud flats, however, the composition of gases of air is altered dramatically. Slight differences occur in the atmosphere at different latitudes and, at places where gases are entering or leaving the atmosphere, such as volcanoes, fires, smelters, cities, metropolitan areas, and vegetation.

Physiologic-ecologic interrelationships of gases and animals—The atmospheric composition is not always the most important factor to organism ; rather, it is the partial pressure of a gas, especially oxygen and CO_2, which influences the existence of life, as illustrated by altitudinal studies on organisms. The **partial pressure** of a gas is the product of the total barometric pressure times the concentration of gas in dry air. For every 18,000 ft., the barometric pressure is reduced by half, but the composition of air is essentially unchanged. To illustrate this effect on animals, the following critical altitudes have been identified for most humans : above 10,000 ft., oxygen must be added to inspired air ; at 35,000 ft., 100 per cent oxygen must be inhaled ; and at 50,000 ft., little oxygen reaches the alveoli even if 100 per cent oxygen is breathed (see **Vernberg** and **Vernberg**, 1970).

The solubility characteristics of oxygen and carbon dioxide in water are different, for carbon dioxide is about 200 times more soluble than oxygen. Both temperature and salinity have pronounced effects on the solubility of these two gases ; with either increased temperature or increased salinity, there is a decrease in solubility in water as has been shown in following table :

Table : Coefficients of saturation of CO_2 in water at different temperatures and salinity (ml/litre in equilibrium with 760mm Hg)

Temperature, °C	Salinity, %		
	0	28·91	36·11
0	1715	1489	1438
12	1118	980	947
24	782	695	677

If gases are to be functionally important to an organism, there must be a mechanism whereby gases can enter and leave the body. Apparently the passage of oxygen across a membrane is accomplished by **diffusion**. The rate of diffusion can be calculated by **Fick's law,** which is based on concentration coefficient, amount of surface thickness of the membrane, and time, and is expressed as the diffusion coefficient (**Davson,** 1959). The diffusion coefficient value is not the same for different animal tissues. For example, some representative values of diffusion coefficient of O_2 are : muscle, 0.000014 ; connective tissue ; 0.0000 11 ; water, 0.000034 ; air, 11.0 ; chitin, 0.000013. Not only is the diffusion rate different in various tissues, but the behaviour of each gas also differs. Carbon dioxide, for example, diffuses through water and animal tissues 25 times faster than oxygen.

Air as a medium for living organism--Air is not a easy and suitable medium to support life (biota) and actually no organism ever originated in air, though, certain aquatic and terrestrial organisms have become secondarily adapted for aerial existence. Air has so much less **buoyancy** than water that organisms emerging from water or land immediately subjected to a stronger pull of **gravity** which hold them to the earth. They are also exposed to **evaporation** of water from their bodies, which threatens loss of water from the protoplasm and death by desiccation. Changes in **temperature** are much more drastic in air and there is great danger of chilling or overheating. Further, periods of light exposure are much longer and much more intense in air than in water or upland. The problem of **mineral supply** becomes acute in the air.

Biota of the air—Only a few micro-organisms, plants and animals have invade the air. The most common examples of aerially adapted animals are—flying fish (*Exocoetus volitans*), flying frog, flying lizard (*Draco volans*), flying phalangers (*Petaurus*), bats (*Eptesicus*), and birds.

B. LITHOSPHERE AND SOIL

The earth is a cooled, spherical, solid planet of solar system, which rotates on its axis and revolve around the sun at a certain

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constant distance. The solid component of earth is called **lithosphere.** The lithosphere is multilayered including following main layers—**crust, mantle,** and **outer** and **inner core.** The **core** is the central fluid or vapourised sphere having diameter of about 2500 kms from the centre and is possibly composed of nickel-Iron. The **mantle** extends about 2900 kms above the core. This is in molten state. The outermost solid zone of the earth is called **crust** which is about 8 to 40 kms above the mantle. The crust is very complex and its surface is covered with **soil** supporting rich and varied biological communites, for living organisms find in the soil an environment providing food, shelter, and concealment from predators (**Wallwork,** 1970).

THE SOIL

The word soil is derived from a Latin word '*solum*' meaning earthy material in which plants grow. The science which deals with the study of soil is called **Soil Science, Pedology** (*pedos*—earth) or **Edaphology** (*edaphos*—soil). The study of soil is significant for us due to various reasons. Soil is a natural habitat for micro-organisms, plants and animals. Its knowledge is helpful in practices of agriculture, horticulture, forestry, etc., such as cultivation, irrigation, artificial drainage, and use of fertilizers. Pedology is important also for geology, petrology, minerology, palaeobotany and paleozoology.

The soil is the loose, friable, unconsolidated top layer of earth crust which is the site of decomposition of organic matter and mineral materials and is the crossroad of terrestrial communities. It provides mechanical anchorage to plants, besides serving as a reservoir of food materials and water. It is the site where nutrient elements are brought into biological circulation by mineral weathering. The soil harbours the bacteria which incorporate atmospheric nitrogen into the soil. Plant roots occupy a considerable portion of the soil ; tie the vegetation to the soil ; and pump water and its dissolved minerals to other parts of the plant for photosynthesis and other biochemical processes (see **Smith,** 1974).

Further, a **mature soil** is that state of soil that has assumed the profile features (*i.e.*, succession of natural layers) characteristic of predominant soils on the smooth uplands within the general climatic and botanic regions in which it is found (**Marbut,** 1926).

SOIL FORMATION OR PEDOGENESIS

Soil, is a stratified mixture of inorganic and organic materials, both of which are decomposition products. The mineral constituents of soil are derived from some parent material, the **soil forming rocks** by fragmentation or weathering, while, organic components of soil are formed either by decomposition (or transformation) of dead remains of plants or animals or through metabolic activities of living organisms present in the soil. Before discussing the soil-forming processes, a brief discussion about the nature of soil forming rocks will be highly desirable :

Soil forming rocks : Basically, there are three kinds of soil forming rocks—**igneous rocks, sedimentary rocks** and **metamorphic rocks.** The main characteristics can be represented in a summarized form in following table :

Table : Classification, characteristics and mineral composition of the principal soil-forming rocks (Wallwork, 1970).

Class of rock	Mode of formation of rock	Type	Description of rock-types	Principle minerals of soil-forming rocks
A. Igneous rocks	Formed by cooling of molten megma (larva)	1. Granite	Usually light in colour, coarse to medium grain	Quarts, feldspar, mica, amphibole, iron oxides
		2. Diorite	Gray to dark in colour, coarse to medium grain	Feldspar, amphibole iron oxide, biotite
		3. Basalt	Dark to black in colour, dense to fine grain	Feldspar, pyroxene, iron oxide, biotite
B. Sedimentary rocks	Formed by deposition of weathered minerals which derived from igneous rocks	1. Shales	Light to dark in colour, thinly laminated	Clay minerals, quartz
		2. Sandstone	Light to red in colour, granular and porous	Quartz, clay minerals, iron oxides, calcium carbonate
		3. Limestone	Light, grey, red, brown, or black in colour, fine grained and compact	Calcite, dolomite, iron oxides, clay minerals
C. Metamorphic rocks	Formed by change of pre-existing rock (*i.e.*, igneous or sedimentary rock) through heat and pressure	1. Gneiss	With light and dark bands	Much as in granite from which it is formed
		2. Schist	Foliated structure	Much as in basalt or shale form which it is formed
		3. Slate	Gry to black in colour, compact and uniform texture	Similar composition to shale form which it is formed

Class of rocks	Mode of formation of rocks	Type	Description of rock-types	Principle minerals of soil-forming rocks
		4. Quartzite	Light to brown in colour, compact and uniform texture.	Similar composition to sandstone from which it is formed.
		5. Marble	Light, red, green or black in colour, compact, fine to coarse texture.	Calcite, dolomite formed from lime stone.

Chemistry of minerals of soil-forming rocks—Rocks are the chemical mixture of numerous kinds of minerals. The chemical nature of certain most common and abundant minerals of soil-forming rocks has been listed in following table :

Table : Chemical composition of some common soil minerals.

Minerals	Chemical Constituents
A. Sand and silt minerals	
1. Quartz or silica	SiO_2
2. Feldspars	
a. Orthoclase	$K_2Al_2Si_6O_{16}$
b. Plagioclase	$NaAlSi_3O_8$
c. Calcium feldespar	$CaAl_2Si_2O_8$
3. Micas	
a. Muscovite	$K(OH)_2Al_2(AlSi_3)O_{10}$
b. Biotite	K,Mg, Fe, Al silicate
4. Pyroxene	$(Mg, Fe) SiO_3$
5. Amphbiole	$(Mg, Fe)_7 (Si_4O_{11})_2 (OH)_2$
6. Olivine and serpentine	$(Mg\ Fe)_2 SiO_4$
7. Calcite ; magnesite ; and dolomite	$CaCO_3$; $MgCO_3$; and ($CaCO_3$, $MgCO_3$)
8. Iron Oxides	
a. Haematite	Fe_2O_3
b, Magnetite	Fe_3O_4
c. Limonite	$FeO(OH), xH_2O$
B. Clay minerals	
1. Kaolin	$Al_2O_3, 2SiO_2, 2H_2O$
2. Montmorillonite	$(Ca, MgO) Al_2O_3, 5SiO_3, 5H_2O$

Besides the tabulated minerals following minerals occur in low percentage in soil-forming rocks—Toarmalive (Boron silicas or Aluminium with alkali metals and Iron and Magnesium), Rutile (Titanium oxides), Zircon (Zirconium oxide), and Gauconite (hydrated silicon of iron and potassium).

PROCESS OF SOIL-FORMATION

The processes which are involved in the formation of mature soil can be studied under following heads :

A. WEATHERING OF SOIL-FORMING ROCKS

Soil formation is started by **disintegration** or **weathering** of parent rocks by some physical, chemical and/or biological agents, because of which the soil-forming rocks are broken down in small particles called **regoliths**. Regoliths are the basic materials which under the influence of various other pedogenic processes finally develop into mature soil.

(a) Physical weathering : The physical weathering agents are primarily climatic in character, exerting a mechanical effect on the substratum with the result that fragments are comminuted into progressively decreasing particle sizes (*i.e.*, regoliths). Such climatic weathering of rocks does not causes any chemical transformation of rock-minerals and commonly occurs in deserts, in high alttiudes, in high latitudes, and inocalities with marked topographic relief and sparse vegetation cover. The agents which are involved in climatic weathering of rocks, are **temperature, water, ice**, **gravity** and **wind** (see **Wallwork**, 1970).

The **temperature** causes break down of those rocks which have heterogeneous structure, due to the fact of differential expansion and contraction coefficient of materials composing the rocks. Minerals composing the rocks have got different degrees of expansion. These minerals expand in the high temperature of day and contract when the temperature falls. The differential expansion and contraction of different minerals of rocks set up internal tensions and produce cracks in the rocks and consequently, the rocks weather into finer particles.

In its liquid state **water** causes mechanical weathering of rocks by following methods : (1) **Rain water**—Natural water falling either in the form of rain drops or hail storm on the surface of rock with beating effect bring about abrasion of massive rocks into smaller particles. (ii) **Torrent water**—Rapidly flowing water rolls the heavy rock masses such as rock boulders along the bottom of stream and grinds them into finer particles. (iii) **Wave action**—The wave actions are most effective in sea shores. The rapidly striking water waves dislocate solid particles of varying diameters from sea shore rocks and the debris is then settled at the sea bottom to form **marine soil**. Water also acts as a mechanical carrier. Nearly 5 billon tons of mineral matter is annually carried away in solution from land to sea (see **Pearse**, 1939).

In its freezing and ice-melting states water causes rock-weathering by **frost action** and **glacier formation**. Water in the form of frost or ice, is an extremely effective physical weathering agent of rocks. It seeps into rock crevices, freezes due to sudden fall of temperature of rocks, expands about nine per cent of its original volume, exerts a pressure (expansion force) of approximately 150 ton/ft^2 and eventually cracks the rock into smaller pieces. Likewise, in summer when ice at mountain tops starts melting and glaciers (huge sliding masses of ice) move downwardly on the slope, then, during the glacier movement, the rock over which they move is gradually worn down to produce fine particles which are deposited as **drift** or **till**, when glacier finally retreats.

Gravitation weathering action is most effectively demonstrated by land slides and rock slippages caused by earth quakes and faulting during which the rock is fragmented by abrasion and the forces of impact. Lastly, the rapid stormy **wind** carrying suspended sand particles causes the abrasion of exposed rock. It acts like a mechanical carrier in moving the particles over the surface of earth as **dunes** or **drifts** and in transporting large quantities of fine suspended particles long distances.

(b) Chemical weathering : The physical disintegration produces a greater surface area of rock exposed to the **chemical weathering**, which occurs simultaneously with physical weathering and continues much beyond that. During chemical weathering, a chemical transformation or decomposition of parental mineral materials into new mineral complexes or secondary products occurs. For example, primary minerals that contain aluminium and silicon, such as feldspar, are converted to secondary mineral such as clay. Because chemical weathering requires the presence of moisture and air as essential factors therefore chemical weathering is not effective in deserts. It includes following reactions :

1. **Solution**—Water is the most potent chemical weathering agent in most kinds of rocks through its solvent action. Solution helps in the removal of water-soluble minerals of weathered rocks. For example, soluble rocks like gypsum, limestone and those with a calcareous content get weathered by the solvent action of water which increases in the presence of CO_2 and organic acids formed by decay of organic remains of plants and animals. The solution of these minerals may become absorbed on the surface of negatively charged colloidal particles or are removed by leaching.

2. **Hydroylsis**—Hydrolysis involves an exchange of constituent parts between water and **minerals** such as the chemical union o water with strong bases producing **hydroxides** of iron, magnesium

calcium, aluminium, etc. Hydrolysis mostly act in combination with other reaction such as oxidation/reduction or carbonation as in the production of secondary kaolinitic clay minerals from primary orthoclase—

$$\underset{\text{Orthoclase}}{K_2Al_2Si_6O_{16}}+2H_2O+CO_2\rightarrow \underset{\text{Kaolin}}{Al_2O_3.2SiO_2.2H_2O}+4SiO_2+K_2CO_3$$

The release of calcium, magnesium, potassium, sodium, and silicates into the soil solution, as a result of hydrolysis, enhances the availability of these ions to plants.

3. **Oxidation**—Oxidation results when oxygen is added to minerals to produce oxides which when dissolves in water weakens the rock and bring about weathering. It occurs in well-aerated, well-drained soil. Because iron is especially reactive with water and oxygen, iron-bearing minerals are prone to rapid decomposition. For example, due to oxidation iron oxidised in the red ferric state.

$$\underset{\text{Ferrous oxide}}{4FeO + O_2} \rightarrow \underset{\text{Ferric oxide}}{2Fe_2O_3}$$

Further, oxides and sulphides of Iron, Aluminium, Manganese, etc., are easily oxidised and cause into the weathering of rocks.

4. **Reduction**—Reduction occurs in wet, badly drained, poorly aerated sites such as deep zones of earth crust. It means removal of oxygen from minerals. For example, red ferric oxide may reduced to the gray ferrous state as follows :

$$2Fe_2O_3 \rightarrow 4FeO + O_2$$

5. **Carbonation :** In carbonation water and carbon dioxide combine to form carbonic acid which reacts with hydroxides of calcium, magnesium and other minerals of rock to form carbonates and bicarbonates in following manner :

(i) $$CO_2 + H_2O \rightarrow \underset{\text{Carbonic acid}}{H_2CO_3}$$

(ii) $$\underset{\text{Calcium hydroxide}}{Ca(OH)_2} + CO_2 \rightarrow \underset{\text{Calcium carbonate}}{CaCO_3} + H_2O + CO_2 \rightarrow \underset{\text{Calcium bicarbonate}}{Ca(HCO_3)_2}$$

The slightly soluble carbonates of these minerals either accumulate deeper in the rock material or are carried away, depending upon the amount of water passing through. The solubility of these carbonates, leaves gaps in rocks and consequently makes them weak enough for weathering process.

6. **Hydration :** During hydration water molecules become chemically attached to particular rock mineral, due to which the volume of parental material increases and hydrated minerals become soft and more readily weatherable :

$$\underset{\text{Hematite}}{2Fe_2O_3} + 3H_2O \rightarrow \underset{\text{Limonite}}{2Fe_2O_3.3H_2O}$$

(c) **Biological Weathering :** Though the surface of bare rock is unsuitable for many forms of life, even then a number of micro oragnisms (bacteria protozoans fungi, nematodes, etc.), lichens and mosses can gain a foothold. These early colonizers transform the rock into a dynamic system, storing energy and synthesizing organic material (**Jacks**, 1965). Their activities alter the mineral composition as well as the physical structure of the rock. For example, lichens are present in the initial stages of biological succession and their growth may cause cracking or flaking, exposing greater area of rock to further weathering. The lichens and mosses extract mineral nutrients such as P, S, Ca, Mg, K, Na, Fe, Si, and Al, from the rock. These elements are combined with organic complexes, and eventually return to the developing soil when the vegetation decomposes.

Products of weathering and soil types : The soil which is formed by weathering of soil-forming rocks is called **embryonic** or **primary soil. The secodary** or **transported** soils are those which are carried to other places by carriers like gravity, water, glacier and wind. Soil material transported from one area to another is known as **loess** or **eolian** ; that transported by water as **alluvial, lacustrine** (lake soil) and **marine deposits** ; that transported by glacial ice as **glacial drift, till** and **moraines** ; that transported by gravity as **colluvial soil** and that transported by sand storms as **sand dunes.** In a few places soil material come from accumulated organic matter as **peat**. The soil which develops *in situ* above parent bedrock is called **residual** or **sedentary soil.**

B. MINERALIZATION AND HUMIFICATION

The decomposition or weathering of inorganic soil matter is followed by decomposition of organic matter which is started at an early stage of pedogenesis, (*i.e.*, the biological weathering) and continues upto much later stages. During early sages of pedogenesis, the organic contents of the embryonic soil are not very high, as the vegetation and its associated fauna are not richly developed. Also, the products of organic composition frequently occur in combination with those of inorganic decomposition as complexes, not easily separable into component parts in these initial stages. However, as both of these decomposition processes develop side by side and in concert, the size of soil particles and the spaces between them become smaller with the result that the water holding capacity increases. This together with the increasing amount of plant nutrients and organic material, allows the soil to support higher plant life, such as grasses ; the protective covering effect and binding action of root systems so provided, promotes a greater stability of soil structure. Thus, soil development begins under some influence of plants. They root, draw nutrients from mineral matter, reproduce and die. Their roots penetrate and further breakdown the regolith. The plants pump up nutrients from its depth and add them to the surface, and in doing so recapture minerals carried deep into the material by weathering processes. By photosynthesis plants capture the sun's energy and add a portion of it as organic carbon to the soil each year. This energy source the plant debris, enables bacteria, fungi (such as *Rhizoctonia solani*, *Armillaria mellea*, etc.), earthworms and other soil organisms to colonize the area.

The breakdown of organic debris into humus is accomplished by decomposition and finally mineralization. Higher organims in the soil—millipedes, centipedes, earthworms, mites, springtails, grasshoppers, and others—consume fresh material and leave partially decomposed products in their excreta. This is further decomposed by micro-oganisms, the bacteria and fungi, into various compounds of carbohydrates, proteins, lignins, fats, waxes, resins and ash. These compounds are broken down into simpler products such as carbon dioxide, water, minerals and salts. This latter process is called **mineralization.** The residual amorphous incompletely decomposed black coloured organic matter which undergoes mineralization is called **humus.** The process of humus formation is called **humification**. **Muller** (1879, 1884) has recognized two kinds of humus—**mor** and **mull. Mor humus** is acidic and supports an abundant fungal growth and low number of soil bacteria. Fungal mycelia may help to bind together particles of humus and decomposition litter into matted layers and in a well developed mor, three such layers can be distinguished, namely a surface litter or **L layer**, comprising undecomposed leaves and twigs, below which is the **fermentation or F layer**, in which decomposition has proceeded same way toward the development of humus, and beneath this, the **humus** or **H layer**, in which degraded humus fractions accumulate. Mor has low calcium content and developed on sandy soils under conifers. **Mull humus** is neutral or slightly alkaline and contain rich microflora of bacteria. It lacks distinct layering of the mor, largely because the presence of calcium compound favour the development of a rich earthworm fauna which promotes a greater mixing of organic and mineral materials. The mull humus develops in brown forest soils under tree species having a relatively high calcium content, such as alder, elm, bass wood, aspen and few conifers (red cedar). Intermediate between the two types of humus is the '**moder**' which has a richer and varied fauna.

In order to emphasize the part played by living plants and animals in soil formation, **Taylor** (1930) proposed the following formula :

$$S = M\ (C + V + VA + A)^{t} + D$$

where, A signifies animals; C=Climate ; D=erosion or deposition ; M=parent material ; S=soil ; t =Time and V=vegetation.

C. FORMATION OF ORGANO-MINERAL COMPLEXES

During final stage of pedogenesis, colloidal particles which are formed due to weathering, humification and mineralization accumulates and may aggregate into **crumbs** or **concretions**. Some colloidal humus particles may become associated with mineral particles to form organo-mineral complexes. According to **Wallwork** (1970) the crumbs or organo-mineral complexes are formed by following two mechanisms—**electro-chemical bonding** and **cementing**. In electro-chemical bonding method of crumb formation, aggregation of negatively charged colloidal clay and/or humus particles of water molecules and metallic ions, particularly calcium, takes place. The cementing mechanism of crumb formation involves the action of substances absorbed on the surface of soil particles which effectively glue them together.

The crumbs increase the total pore space in the soil, allowing good aeration and drainage. Eventually, a characteristic profile develops under the influence of climate, vegetation, parent material and the activities of the soil communities. The mature soil, thus, becomes a complex system of living and non-living materials not inert but active.

SOIL PROFILE

Soil profile is the term used for the vertical section of earth crust generally upto the depth of 6ft or upto the parent material to show different layers or horizons of soil for the study of soil in its undisturbed state. It is made up of a succession of horizontal layers or **horizons**, each of which varies in thickness, colour, texture, structure, consistency, porosity, acidity and composition.

In general soils have following four horizons an **organic** or **O-horizon** and three **mineral (A, B, C) horizons.** Some workers recognized a **D horizon**, in which rocks are in active weathering state, in between C and R horizons. **R horizon** is the consolidated bed rock on which a soil profile rests. A and B horizons form the **true soil** or **solum**. Each horizon of soil profile is further subdivided. Horizon subdivisions are indicated by arabic numbers, *e.g.*, O_1, O_2,

A_1, A_2, etc. Different horizons of soil-profile have following characteristics :

(i) **O–horizon**—The O-horizon, once designated as L, F, H, or Ao and Aoo, is the surface layer forming above the mineral layers and composed of fresh or partially decomposed organic material, as found in temperate forest soils. It is usually absent in cultivated soil. O-horizon contains both kinds of humus (*e.g.*, mull and mor)

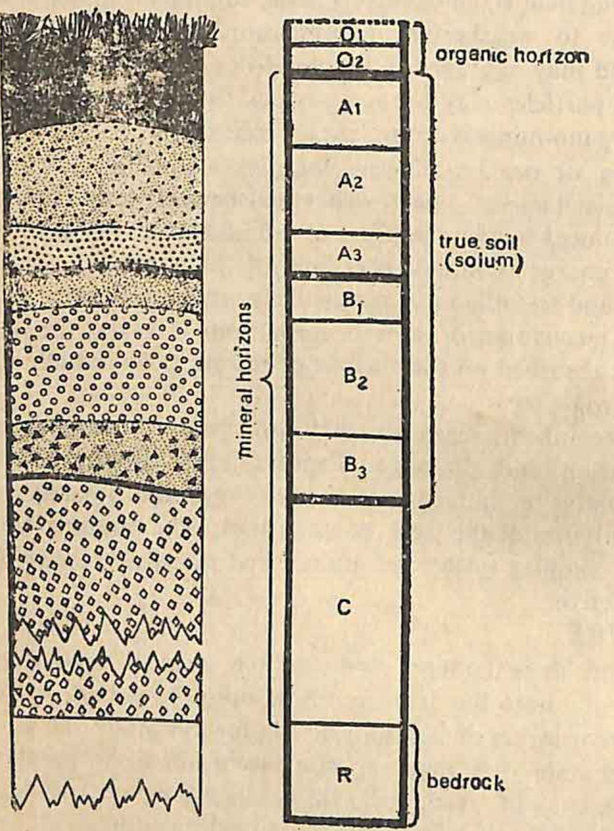

Fig. 2·1. A generalized profile of soil. O_1 : Louse leaves and organic debris : O_2 : organic debris partly decomposed or matted. A_1 : A dark coloured horizon with a high content of organic matter mixed with mineral matter. A_2 : A light-coloured horizon of maximum leaching. A_3 : Trasitional to B but more like A than B. B_1 : Transitional to B but more like A than B. B_2 : A deeper coloured horizon of maximum accumulation of clay minerals or of iron and organic matter. B_3 : Transitional to C. C : Weathered material (regolith). R Consolidated bedrock (Smith, 1974).

and is subjected to the greatest changes in soil temperatures and moisture conditions and contains most organic carbon. O-horizon and upper part of A horizon is the region where life is most abundant.

(ii) **A-horizon**—It is characterized by major organic matter accumulation, by the loss of clay, iron and aluminium and by the development of organo-mineral complexes, granular crumbs or platy structures.

(iii) **B-horizon**—It lies below A horizon and also called **sub-soil**. It is characterized by an alluvial concentration of all or any of the silicates, clay, iron, aluminium, and humus, alone or in combination and by the development of blocky, prismatic or columnar structure.

(iv) **C-horizon**—Below B-horizon and above the surface of weathered parent rock, is the zone of regolith or C-horizon. It is a light-coloured horizon containing weathered parent material.

(v) **R-horizon**—Below all these horizons may lie the **R-horizon,** which is the region of consolidated rock.

MORPHOLOGY OF SOIL

In the field, differences among soils and among horizons within a soil are primarily reflected by variations in texture, arrangement, structure and colour.

1. **Texture of soil**—The texture of a soil is determined by the production of different sized soil particles. Mineral fractions or particles of soil are called **"soil fractions"** or **"soil separates"**. The soil particles have been classified into **gravel, sand,** and **clay** on the basis of their size differences. Gravel consists of coarse particles larger than 2·0 mm. Sand ranges from 0·02 to 2·0 mm in diameter and is easily seen and feels gritty. Silt consists of particles from 0·002 to 0·02 mm in diameter, which scarcely can be seen by the naked eye, feels and looks like flour. Clay particles range below 0·002 mm in diameter, are too fine to be seen even under the ordinary microscope, and are colloidal in nature. Clay controls the most important properties of soils, including plasticity and exchange of ions be ween soil particles and soil solution.

Most soils are a mixture of these various particles. Based on the proportions of the various particles contained in them, soils can be grouped into 5 textural groups : (1) **Coarse textured soils** are loose, consist mainly of sand and gravel. They retain very little moisture and supply some plant nutrients. (2) **Moderately coarse soils** includes sandy loam to very fine sandy loam. (3) **Medium textured soils** are mixture of sand, silt and clay high enough to hold water and plant nutrients. (4) **Moderately fine textured soils** are high in clay. They are moderately sticky and plastic when wet, they may form a crust on the surface if organic matter is low. They have a high moisture-holding capacity. **(5) Fine textured soils** contain more than 40 per cent clay, may be sticky and plastic when wet and hold considerable water and plant nutrients, but may have restricted internal drainage. All these 5 textural soil-groups include following 12 textural classes which have been recognized on the basis of relative percentages of soil particles (*i.e.*, sand, silt and clay) :

Table : Textural classes of soils.

Soil classes or Textural names	Range in relative percentage of soil		Separates
	Sand	Silt	Clay
1. Sandy soil	85—100	0—15	0—10
2. Loamy sand	70—90	0—30	0—15
3. Sandy loam	43—80	0—50	0—20
4. Loam	23—52	28—50	7—27
5. Silt loam	0—50	50—88	0—27
6. Silt	0—20	8—10	0—12
7. Sandy clay loam	45—80	0—28	20—35
8. Clay loam	20—45	15—53	27—40
9. Silty clay loam	0—20	40—73	27—40
10. Sandy clay	45—65	0—20	35—45
11. Silt clay	0—20	40—60	40—60
12. Clay	0—45	0—40	40—100

2. Structure of soil—Soil separates (sand, silt and clay) are held together in clusters or shapes of various sizes, called **aggregates** or **peds.** The arrangement of these peds in earth crust is called **soil structure.** Like texture, there are many types of soil structure. Soil peds may be classified as **granular, crumb-like, plate-like** or **platy, blocky, prismatic** and **columnar.** The properties of different soil peds can be tubulated in following table :

Table : Characteristics of peds.

Types of ped	Properties
1. Granular	Small, spherical and non-porous.
2. Crumb-like	Small, porous and spheroidal.
3. Agranular blocky	Block-like with sharp ends, one end may be pointed.
4. Sub-granular blocky	Block-like but bounded by other aggregates.
5. Platy	Plate-like, sometimes plates are overlapped.
6. Prismatic or columnar	Prism-like but without rounded surface.

Structureless soil can be either single-grained or massive soil aggregates (peds) tend to become larger with increasing depth. Structure is influenced by texture, air, moisture, organic nutrients, micro-organisms, root-growth and soil chemical status.

3. **Soil colour**—Soils exhibit a variety of colours. Soil colour may be inherited from the parental material (*i.e.*, **lithochromic**) or sometimes it may be due to soil forming processes (**acquired or genetic colour**). Though colour has little direct influence on the functions of a soil, but is important in the identification of soil type. In temperate regions dark-coloured soils generally are higher in organic matter than light coloured ones. Well-drained soil may range anywhere from very pale brown to dark brown and black, depending upon the organic matter-content. Red and yellow soils are the result of iron oxides, the bright colours indicating good drainage and good aeration. Other red soils obtain their colour from parent material and not from soil-forming processes. Well-drained yellowish sands are white sands containing a small amount of organic matter and such colouring matter as iron oxide. Red and yellow colours increase from the cool regions to the equator. Quartz, kaolin, carbonates of lime and magnesium, gypsum and various compounds of ferrous iron give whitish and grayish colours to the soil. The grayest are permanently saturated soils in which the iron is in the ferrous form.

Soil colour and temperature—Soil colour influences the soil temperature. The dark coloured soils absorb heat more readily than light coloured soils. **Ramdas** *et. al.*, (1936) showed that black cotton soils of Poona absorbed 86% of the total solar radiations falling on the soil surface as against 40% by the grey alluvial soil.

PHYSICAL PROPERTIES OF SOIL

Soil possesses many characteristic physical properties like density, porosity, permeability, temperature, water and atmosphere, each of which can be studied under following separate headings :

1. **Soil density**—Average density of soil is 2·65 gms. per ml. Density of soil varies greatly depending upon the degree of weathering.

2. Porosity—The space present between soil particles in a given volume of soil are called **pore spaces**. The percentage of soil volume occupied by pore space or by the interestitial spaces is called **porosity** of the soil. Porosity of soil depends upon the texture and structure compactness and organic contents of soil. Porosity of the soil increases with the increase in the percentage of organic matter in the soil.

The pore spaces are of two types—**(1) Micro-pore spaces** (capillary pore spaces) and **(2) Macro-pore spaces** (non-capillary pore spaces). Capillary pore spaces can hold more water and restrict the free movement of water and air to a considerable extent, whereas macro-pore spaces have little water holding capacity and allow free movement of moisture and air in the soil under normal conditions.

3. Permeability of soil—The characteristic of soil that determines the movement of water through pore spaces is known as **soil permeability**. Soil permeability is directly dependent on the pore size, therefore, it is higher for the loose soil with large number of macro-pore spaces than it is for compact soil with numerous micro-pore spaces.

5. Soil temperature—Soil gets its heat energy from different sources such as solar radiation, decomposing organic matter, and heat formed in the interior of earth. The temperature of soil is effected by its colour, texture, water content, slope, altitude of the land and also by climate and vegetational cover of the soil. Evaporation of water from soil makes it cooler. Black soils absorb more heat than white soils. Sandy soils absorb more heat and radiate it out quickly at night than clay or loam soils.

The soil temperature greatly affect the physico-chemical and biological processes in the soil. For example, the germination of seeds, normal growth of roots and biological activity of soil-inhabiting micro-and macro-organism require proper and specific temperature.

6. Soil water—In soil, water is not only important as a solvent and transporting agent but in various ways it maintains soil texture, arrangement and compactness of soil particles and makes soil habitat livable for plants and animals. It comes in soil mainly through infilteration of precipitated water (dew, rain, sleet, snow, and hail) and irrigation. According to improved classification method of **Bouyoucos** (1920), soil water is classified into following types—gravitational and ground water, capillary water, hygroscopic water, combined water and water vapour.

(i) Gravitational water—In a well-saturated soil, the accessory (extra) amount of water displaces air from the pore spaces between soil particles and percolates downwardly under gravitational influence and finally it is accumulated in the pore spaces. This accumulated excess water of large soil spaces is called **gravitational water**. When this gravitational water further percolates down and reaches to the level of parent rock, it is called **ground water**. Both kinds of these soil waters are ecologically important in the leaching of nutrients

(ii) Capillary water—The water which held by capillary forces (*i.e.*, surface tension and attraction forces of water molecules) in smaller soil channels, when the gravitational water and ground water has been drained, is called **capillary water**. Capillary water occurs as a thin-film around soil particles in the capillary spaces and represents the normal available water to the plants. It remains in soil for long periods and carries with it nutrients in solution. Humus has more capillary water than soil minerals.

(iii) Hygroscopic water—Soil particles retain some water so tenaciously that the plants cannot absorb this. Such soil water is called hygroscopic water.

(iv) Combined water—Combined water is the water of chemical compounds held by chemical forces of molecules such as hydroxides of silicon, iron and aluminium. It is of no ecological significance.

(v) Water vapour—Some soil water occurs as moisture or water vapours in the soil atmosphere.

Further, the total amount of water present in the soil is called **holard**. The quantity of water that plant-roots can absorb out of holard is called **chresard** and that amount of soil water which cannot be absorbed by plant-roots is called **echard**.

6. **Soil atmosphere**—Gases found in pore spaces of soil profiles form the **soil atmosphere**. The soil atmosphere contain three main gases namely O_2, CO_2, and N_2. Soil air differs from atmospheric air in having more of moisture and CO_2 and less of O_2. The soil atmosphere is affected by temperature, atmospheric pressure, wind, rainfall, etc. Loam soils with humus contains a normal proportion of air and water (about 34% air and 66% water) and therefore are good for majority of crops.

CHEMICAL PROPERTIES OF SOIL

Soil is a mixture of various inorganic and organic chemical compounds and exhibits certain significant chemical properties, all of which can be discussed as follows :

(a) Inorganic elements and compounds of soil : The chief inorganic constituents of soils are the compounds of following elements—Al, Si, Ca, Mg, Fe, K and Na. Soil also contains smaller amounts of compounds of following inorganic elements—B, Mn, Cu, Zn, Mo, Co, I, F, etc.

(b) **Organic matter of soil :** The cheif organic component of soil is **humus** which chemically contains—amino acids, proteins, purines, pyrimidines, aromatic compounds, hexose sugars, sugar alcohols, methyl sugars, fats, oils, waxes, resins, tannins, lignin and some pigments. Further humus is black coloured, odourless, homogeneous complex substance.

(c) **Colloidal properties :** As soil is composed of crystalloids and colloids, therefore, it exhibits all the physico-chemical properties which are related with these two soil particles. Colloids for example exhibit adsorption, electrical properties, coagulation, Tyndal phenomenon, Brownian movement, dialysis, etc.

(d) **Soil pH :** Many chemical properties of soils centre around soil reaction. As regards their nature, some soils are **neutral**, some are **acidic** and some **basic.** The acidity, alkalinity and neutrality of soils are described in terms of hydrogen-ion concentrations or pH values. A pH value of 7·0 indicates neutrality, a value above this figure (7·1—14·00) indicates alkaline conditions and a value below (0—6·9) indicates acid conditions. Normally, the pH value of soils lies between 2·2 and 9·6. In India, acidic soils (pH below 5·5 to 5·6) occur in the high rainfall areas of Western ghats, Kerala. Eastern Orissa, West Bengal, Tripura, Manipur and Assam. The saline, alkali or basic soils (called '*Usar*', contain pH upto 8·5) of India, occur in U.P., West Bengal, Punjab, Bihar, Orissa, Maharashtra, Madras, M. P., A.P., Gujrat, Delhi and Rajasthan.

Highly acidic and highly saline or alkaline soils often remain injurious for plant growth, micro-organisms, etc. Neutral or slightly acidic soil, however, remain best for the growth of majority of plants.

CLASSIFICATION OF SOILS

Soils are of various types as regards to their physical, chemical and biological properties. Similar to biology, in pedology, soils are classified into orders, suborders, great soil groups and subgroups, etc. All of these can be summarized in following table :

Table : Classification of soils.

Soil order	Soil sub-order	Great soil groups
A. Zonal soils	1. Humid region	(i) Podozolic yellow soil with black humic top soils. (ii) Red yellow podozolic soils.

Soil order	Soil Sub-order	Great soil groups
		(iii) Non-laterised red soils.
		(iv) Laterised red soils.
		(v) Degraded grey and black clay soils.
		(vi) Alluvial soils.
	2. Arid region (Desert soils)	(i) Red desert soils.
		(ii) Dark soil.
B. Interzonal soils	1. Calcimorphic (calcareous soils)	(i) Red soil (developed over limestone).
		(ii) Black soil (developed over limestone).
		(iii) Red soil (developed over marls)
		(iv) Black soil.
	2. Holomorphic	(i) Saline soil
	3. Hydromorphic	(i) Ground water lateritic soil.
		(ii) Planosols.
		(iii) Organic soils.
C. Azonal soils	1. Lethosols	
	2. Regosols	
	3. Alluvial soil.	

MAJOR SOIL TYPES OF INDIA

Geographically soils of India are divided into three groups—1. Mature soils of Peninsular India (Include red soils, black soils, lateritic soil). 2. Alluvial soils of Indogangetic plain. 3. Scanty soil, of Himalayas. Further, in India the alluvial soils occurs in the belt of the submountain regions running along the base of the Himalayas (in Punjab, Uttar Pradesh, Bihar, West Bengal) and valleys of Narmada, Tapti (Madhya Pradesh), Godavari, Krishna and Cauvery. The black cotton soils occur in West Madhya Pradesh, Maharashtra, parts of Andhra, Bihar, West Bengal, Assam, Tamilnadu, Orissa, etc. Red soils occur in large areas of Madras, Mysore, North East Andhra and other regions. Laterites and lateritic soils on the summit hills of Deccan, Madhya Pradesh, eastern Ghats, parts of Orissa, Assam, Mysore and Kerala. Besides these there are mountain soils, desert soils, peaty and other organic soils. Peaty soils are mostly found in Kerala. They are black and acidic (pH 3·9).

SOIL AS HABITATS FOR ANIMALS

Soil is used by various animals as a refuge from enemies, to escape desiccation and extremes of temperature ; as material for abodes, and as a highway. Clay is cold, dense, poorly aerated and though it holds much water, does not give up water readily to plants and animals. Sand is dry, loose (cave in readily) and has a variable temperature. Rock heats and cools quickly, has little available water and practically no air, and is usually too resistant to allow penetration by burrowing animals. Alkaline soils are "physiologically dry" because the salts present hold the water so that it is not readily available to organisms. Humus has a great water capacity and gives up water readily, is usully well-aerated and furnishes nitrogen as well as mineral salts and water. It remains rich in biota. Peaty soils are raw humus and are uninhabitable for most animals because they are poorly aerated and have an acid reaction. In general, the character of the vegetation cover serves as a good index of the habitability of soils for animals; conditions that make plants flourish are usually favourable for animals.

SOIL FAUNA AND SOIL FLORA

Soil supports a wide array of organisms of different body-sizes and taxonomic groups. Generally, soil organisms are classified into three major groups namely **micro-fauna** and **micro-flora**, **meso-fauna**, and **macro-fauna**. Mesoflora and macroflora because occur above the surface of soil (land-surface), therefore, are excluded from this discussion :

1. **Microfauna**—It includes animals with body size within the range of 20μ to 200μ. It includes all Protozoa and small-sized mites, nematodes, rotifers, tardigrades and copepode Crustacea. Soil inhabiting **protozoans** like amoeba, ciliates, zoomastigine flagellates occur near the surface soils, while the testate forms like *Thecamoeba*, *Euglypha* and *Difflugia*, have a wider vertical distribution. The common terrestrial **polyclad** is *Bipalium*. The **nematodes** such as *Rhabditis*, *Diplogaster*, *Tylenchus*, *Heterodera*, *Aphelenchoides*, *Mononchus*, *Pratylenchus*, *Xiphinema* and *Criconemoides*, abound by as much as 1–3 million in raw humus soils to 20 million/m_2 in grass land soils.

2. **Microflora**—The microflora of soil includes bacteria, soil fungi, soil actinomycetes, blue green algae and algae. In soil, microflora bacteria form about 90 per cent of the total population. Fungi and algae together represent one per cent and actinomycetes cover only 9 per cent,

Soil bacteria grow fairly well in the neutral soils richly supplied with organic nutrients. Soil inhabitant bacteria fall into two categories namely—**autotrophic bacteria** and **heterotrophic bacteria.** The autotrophic bacteria derive their energy from the oxidation of simple carbon compounds or from inorganic substances and their carbon from the atmospheric CO_2. The common autotrophic bacteria of soil are nitrifying bacteria, hydrogen bacteria, sulfur bacteria, iron bacteria, manganese bacteria, carbon monoxide bacteria and methane bacteria. Most of soil bacteria are heterotrophic bacteria depending upon the organic matter of soil for their energy source and are primarily concerned with the decomposition of cellulose, and other carbohydrates, proteins, fats and waxes. They bring about mineralization of organic matter of soil and release considerable amount of nitrogen, phosphorus and other nutrients for plants. The common nitrogen-fixing bacteria of soil are *Rhizobium* (occurs in root nodules of leguminous plants); *Azobacter* and *Clostridium pasteurianum* (the latter two are free occurring in soil).

Majority of **soil fungi** are found in acidic soils. They may be parasitic, saprophytic and symbiotic. **Parasitic fungi** of soil infect roots of plants and cause plant diseases such as cotton root rot and many kinds of wilts, rusts, blights and smuts. Certain wilt-forming fungi produce toxins which are harmful, for example, *Fusarium lini*, which causes wilt of flax (*Alsi*) secrets HCN and *Fusarium udum*, a fungus causing wilt of pigeon pea (*Arhar*) secretes fusaric acid in the roots of host plants. However, certain parasitic fungi produce growth stimulating substances for host plant. *Fusarium* sp., for example, have been found to secrete Gibberellin and Gibberellic acid ($C_{19}H_{22}O_6$). **Symbiotic fungi** of soil live on the roots of certain plants and both fungus and plants are benefitted. **Saprophytic fungi** depends on dead organic matter of soil and derive their energy from decomposition of the latter. They break down cellulose, lignin, and gum, sugars, starch, protein, etc., into simple gradients to be utilized by higher plants or nutrients.

Actinomycete fungi prefer saline soils and bring about the decomposition of organic matter such as cellulose. They produce a variety of antibiotics of great economic significance for man. The most important blue green algae of soil are those which fix nitrogen in soil. *Anabaena*, *Nostoc*, *Microcystis* are important nitrogen fixing blue green algae of soil. They also make soil aggregates because of having mucilage.

3. **Mesofauna**—Mesofauna include animals with body size within the range of 200μ to 1 cm. The micro-arthropods Acari (mites) and Collembola (spring tails) are important member of this group which also includes the larger nematodes, rotifers, and tardigrades, together with most of the isopods, Araneida (spiders), Chelognethi (pseudoscorpions), Opiliones (harvestmen), Enchytraeidae (potworms), insect larvae and smaller millipedes (Diplopoda), isopods and molluscs.

Among **annelids** the microscopic enchytraeids ore represented by *Enchytraeus fridericia* and *Achaeta lumbricellus*, which are more abundant in organic soils and forests than in grass land. *Oniscus*, *Porcellio*, and *Armadillidum* are the most common isopods (**crustacean**) of the tropics in the humid zone. Among the soil

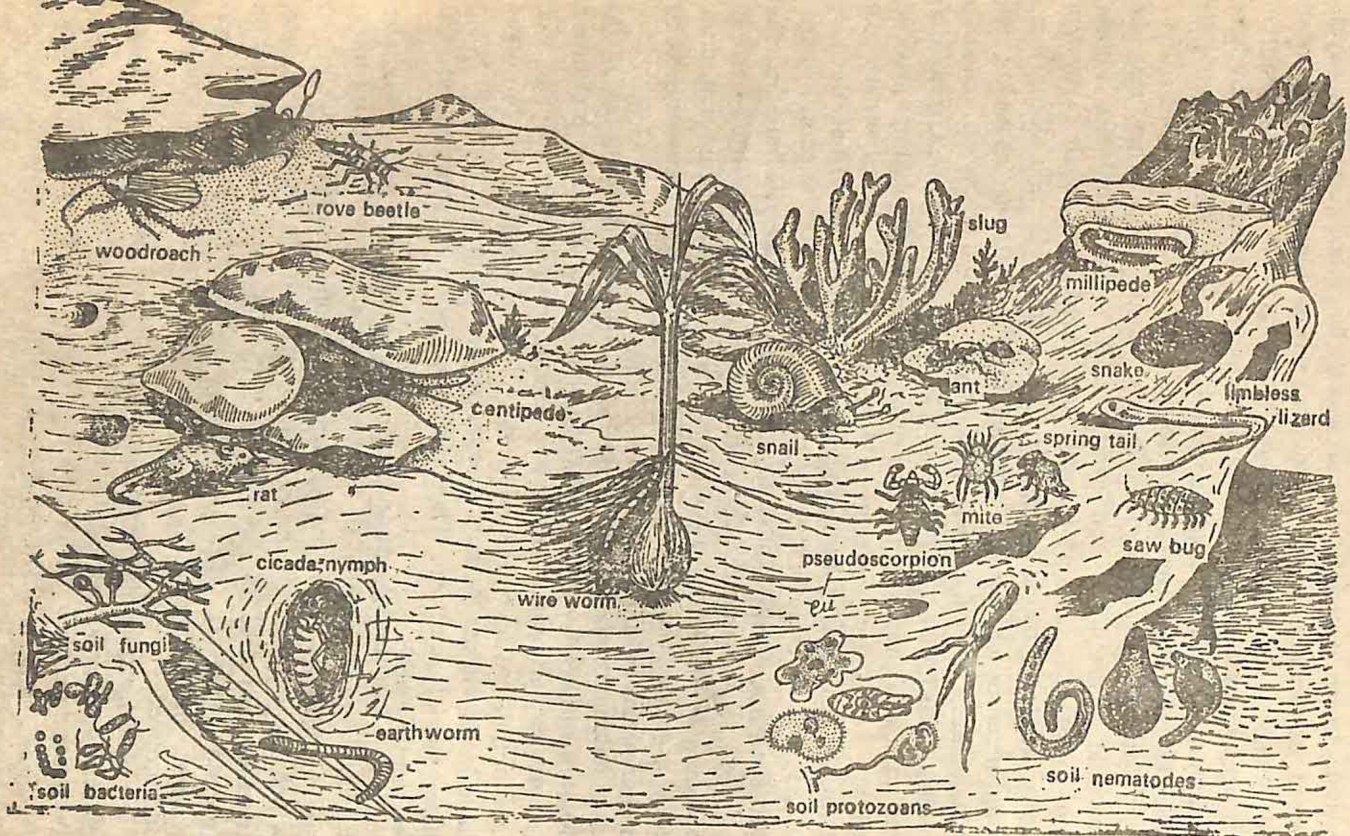

Fig. 2·2. Certain most common living organisms (biota) inhabiting the soil (Smith, 1974).

arachnids, mites are the most predominant. Mites flourish in moist organic soils and certain mites such as *Galumna*, *Cepheus*, *Hemorobates* occur in lichens and mosses. Certain mites, such as, *Schelorbates* and *Brachychthornus* live in humus. The mites are saprophagous, predatory and phytophagous and are involved in the process of organic decomposition and its resultant processes. Certain arachnids like scorpions, *Thelyphonus*, *Galeodes*, and some spiders are crepuscular, hiding under rocks or in crevices in soil and in loose litter, and has no ecological significance in decomposition like other arachnids. Many **opiliones** or harvestmen occur in forest litter, frequently preying upon soil organisms.

Besides mites, only the pseudoscorpions or **chelognathae** occur in surface soils and most decaying vegetations. Of the xerophil litter inhabitants are *Stenatemnus indicus*, *Dhanus indicus*, *Fealla indica* and the hygrophil inhabitants living in the litter and under stones are—*Comsaditha indica*, *Tyrannochthonius madrasensis*, *Tyrannochithonius chelatus* and *Hygrochelifer indicus* (**Murthy**, 1964), feeding on Collembola, enchytraeids, etc.

The common millipedes or diplopodes of forest soil which are chief decomposers of soils are *Spirostreptus*, *Thyropygus*, *Glomeris*, *Arthrosphaera*, *Polydesmus*, *Iulis*, etc. **Tardigrades** or bear animalcules occur in surface layer of moist soils in grassland and being represented by the *Macrobiotus* and *Hypsibius*.

Among **insects**, apterygote Collembola form numerically the most important groups of soil insects. Others like Dermaptera, psocids, Dictyoptera, Isoptera, Coleoptera, a few Hymenoptera and some Diptera also occur in soil, sometimes as juveniles. The termites such as *Reticulotermes* and *Odontotermes* are important soil-dwellers of tropics and play an important role in the break up of organic materials and their mixing up with mineral soils. Among the Hymenoptera, ants are the most important soil dwelling forms. Among Collembola, Onchuridae, Isotomidae, Poduridae, and Entomobrydae are richly represented in the soil both in number and species composition. Large-sized Collumbola such as *Tomocerus*, *Entomobrya* and *Orchesella* occur in surface layer, while the smaller *Onychurus*, *Tullbergia*, etc., occur in deeper layers of soils.

Among Diplura (**Mollusca**), *Anajapyx*, *Japyx* and *Campodea* are often found in small numbers in moist soils under stones and in humus. Proturans are more abundant than Diplura and very common in moist forest and grassland soils which abound in species of *Eosentomon*, *Acerentomon* and *Acerentulus*.

4. Macrofauna of soil : Macrofauna of soil includes those animals whose body size is greater than 1 cm. Here belong the majority of Lumbricidae, the Mollusca, the largest insects and arachnids and the soil-dwelling vertebrates.

Earthworms usually occur in abundance in alkaline and moist soils and sparse in acid soils. They have been proverbial for their influence on the process of decomposition of organic materials, breaking up litter fragments and mixing them throughly with mineral soils resulting in the formation of organic soils. Some of the common Indian annelidan species of soil are *Megascolex*, *Pheretima*. *Octochaetus*, *Drawida* and *Moniligaster*. Among chilopods the carnivorous *Scolopendra* and *Lithobius* are common in moist soils feeding on leaf litter inhabitants.

Among soil vertebrates, following animals are well adopted for burrowing life in soils—*Ichthyophis*, *Cacopus systema*, *Breviceps* (Amphibia), *Sphenodon*, *Uromastix*, limbless lizards and snakes (Reptilia), *Talpa*, *Dasyurus*, *Notoryctes* and various insectivores and rodents (Mammalia).

C. HYDROSPHERE AND WATER

About three-fourth of the earth's surface (71%) is covered with **hydrosphere**, the main component of which is **water**. Water is one of the most unusual natural compounds found on earth, and it is also one of the most important. Life on earth began in the seas, and water in some form or other is absolutely essential to the maintenance of all life. Water is one of the main agent in pedogenesis (soil formation) and is the medium for several different ecosystems. It permeates the atmosphere and the outer layers of lithosphere and has uneven distribution on earth, so that, some of the great ocean depths are approximately six or seven miles (9750 meters). Further, water in its two forms, salt water and fresh water, forms two chief aquatic environments—namely **marine environment** and **fresh water environment** of earth. The oceans holding marine environment are two and one half times more extensive than land and provide over 300 times the living space, since they are habitable throughout their entire depth by certain groups of organisms. Water is obviously heavier than air which imparts a greater buoyancy to the aquatic medium, enabling organisms to float at variable levels. The most unique features of water concern its physical properties.

PHYSICAL PROPERTIES OF WATER

Henderson (1913, 1924) listed in his stimulating book, *The Fitness of the Environment*, the following characteristics of water which are favourable to biological systems :

1. A tremandous quantity of water exists on earth in three forms : gaseous, liquid, and solid. Not only is 75 per cent of the earth's surface covered by water but the atmosphere also contains an abundance of aqueous vapour, and the polar region is ice-covered. Moreover, at least 60 per cent of active protoplasm is water.

2. Water is an extremely inert body in relation to most other chemical substances.

3. It has unique thermal properties such as heat capacity, latent heat and higher freezing point.

(a) **Heat capacity :** Water has high heat capacity and it can withhold large amounts of heat. Because of the high heat capacity of water, oceans and lakes tend to maintain a relatively constant temperature, and therefore the temperature of the biosphere is relatively stable. This property of water is functionally important to animal life. For example, a 165lb. man at rest produces sufficient heat to raise his body temperature more than 32°C, but if the heat capacity of his body were to correspond to that of many other substances, this amount of heat production would raise his temperature 100–150°C.

(b) **Latent heat of melting and evaporation :** The latent heat of melting is the number of calories required to convert 1 gram of solid at the freezing point into 1 gram of liquid at the same temperature. This value is about 90 for water, and means that the amount of heat necessary to melt ice is the same as that required to raise the temperature of the resulting ice water to 80°C. The latent heat of evaporation is defined as the number of calories required to change 1 gram of liquid into vapour. For water this value is 536; therefore as much heat is required to boil away 1 gram of water as to raise the temperature of 536 grams through 1°C. These properties of water are important not only because they moderate the temperature of the biosphere, but also because they play a basic role in the evaporation of water and its precipitation as rain and as dew in the **hydrological (water) cycle.**

(c) **Thermal conductivity :** Although water is a poor thermal conductor compared to metals, among the common liquids it is excellent : for example. the conductivity value for silver is 1·10, for water, 0·0125, for alcohol, 0·00048, and for benzene, 0·00033.

(d) **Expansion before freezing :** The relationship between temperature and density, or mass per unit volume, is very unusual. When water is cooled from room temperature, it contracts, becoming denser until it reaches a maximum density at 3·94°C. If cooled further, it begins to expand again. At the freezing point (0°C) it expands markedly, unlike almost all other substances. Thus ice will always float on the top of a lake or stream, and it is very unusual for an aquatic ecosystem ever to freeze solid, unless it is very small.

4. No other compound compares to water as a **solvent**. So many different substances can be dissolved in it that it is known as the **universal solvent**. More things, in fact, can be dissolved in water than in any other liquid. This is especially true of inorganic chemicals which split, or dissociate to form electrically charged entities termed **ions**. Ionization influences most electrical phenomena and many chemical phenomena of solutions. It is probable that all natural elements are soluble in water, at least in trace amounts, and that they are all found in natural water at some place or other on the earth's surface. In addition, many organic chemicals are water-soluble. Thus, water is the main medium by which chemical constituents are transported from one part of an ecosystem to the other. It is the only medium by which these constituents can pass from the abiotic portion of the ecosystem into the living portion. Even in the driest of terrestrial environments, nutrient materials pass into the roots of plants in aqueous solution; when air is breathed by animals, oxygen is dissolved in water at the surface of the lung before it can cross the mucous membrane and be absorbed by the blood.

5. Water has the greatest **surface tension** of all common liquids, except mercury. The role of surface tension is most obvious in the way it allows certain things, such as pollen, dust, and water striders, to remain at the surface of a water body even though they are denser than the water. More important however, the high surface tension of water allows soils to contain a significant amount of water through capillary attraction and to make it avilable to terrestrial plants. In addition, surface tension has profound effect on certain basic physiological and biochemical reactions within living organisms.

Visualizing these unique physical properties of water, **Henderson** (1913, 1914) concluded that no other known substance could be substituted for water as a basic abiotic environmental factor. Now, ecologists have known certain other important physical properties of water which affect life in someway. Some of the additional important physico-chemical properties of water are following :

(i) Viscosity : Water is a fairly viscous liquid. Animals that live and move in water need to be much more streamlined than those that move through air, because the resistance to motion in a viscous medium is high. But at the same time, the viscocity of water allows organisms to swim using relatively simple movements.

Further, high viscosity of water protects the aquatic animals and plants from the mechanical disturbances.

(ii) Buoyancy : Water is a buoyant medium. Organisms can exist in it without specialized supportive structures such as are needed by organisms that inhabit terrestrial environments.

(iii) Transparency : Water is a transparent medium. Its transparency enables the penetration of light to the depths where it is ultimately absorbed. Different wave lenghts are absorbed at different depths. The long heat waves are stopped near the surface. Shorter waves with more energy penetrate successively farther. The ultraviolet rays penetrate beyond 100 meters. The zone upto which light rays penetrate is called as **photic zone** and below this zone there is complete darkness and organisms that require light cannot live. The transparency of water is greatly affected by the presence of suspended particles, phytoplankton, etc., which absorb light and so penetration of light in turbid water is less.

(iv) Pressure : Organisms living at sea level experience a pressure of about 15 psi, which is defined as 1 atm (760 mm of Hg). Pressures increase with increased depth of water at the rate of one atmosphere (1 atm) for every 10 meters of descent. Organisms inhabiting the floor of deep-sea areas at depth of 10,500 meters are exposed to hydrostatic pressure of about one ton per square centimeter. Pressure influences solubility, ionic dissociation, and surface tension, and water is slightly compressible with increased pressures.

(v) Salinity : Salinity has been defined as "the total amount of solid material in grams contained in one kilogram of the water, when all the carbonate has been converted into oxide, bromine and iodine replaced by chlorine and all organic matter completely oxidised." All types of natural waters contain various amounts of differents salts (ions) such as Na, K, Mg, Cl, SO_4, PO_4. CO_3; HCO_3, NO_3, etc. and all these salts are responsible for the **saltiness, salinity or salt content** of water. The salinity of marine water is rather constant being about 3·5%. The salinity of fresh water varies greatly. Some salt lakes may have a salinity of 25% to 30% which greatly restricts life in them.

Table : Comparison of some of the principal ions found in different kinds of water.

Water	Na	K	Ca	Mg	Cl	SO_4	CO_3	Total per liter
1. Soft water	0·016	—	0·01	0·0005	0·019	0 007	0·012	0·065
2. Hard fresh	0 021	0·016	0·62	0·014	0·041	0·025	0·119	0·301
3. Sea	10·56	0·30	0·40	1·27	18·98	2 65	0·71	34 85
4. Great salt lake	65·54	3·76	0·065	4·47	110·08	13·04		197·51

Salinity of water acts as an important limiting factor for the distribution of a number of species of plants and animals. Certain animals such as, spider crab, *Maia*, etc., can tolerate only narrow fluctuations in salinity of water and are known as **stenohaline** animals. While some animals such as *Mytilus*, *Aplysia* etc., can withstand wider ranges of salinity and are called **euryhaline** animals. However, there are certain animals, such as, *Anguilla*, *Salmon*, etc., which are both stenohaline and euryhaline.

CHEMICAL PROPERTIES OF WATER

Water consists primarily of a single compound, H_2O. It is a universal solvent and most chemical compounds ionize readily in water and provide many radicals and considerable versatility in the rearrangement of chemical substances. It has following chemical properties :

a. Solubility of gases in water : Most gases dissolve readily in water, most notably those that are essential for life. The concentration of any gas in water generally varies between zero and a theoretical maximum or **saturation**. The latter is the amount of gas that can be dissolved in water when the atmosphere and the water are in equilibrium with one another. Except for water falls and very turbulent streams, the water in natural ecosystem is seldom in equilibrium with the atmosphere. A gas may show a **deficit**, if it is being utilized in the ecosystem faster than it is going into solution across the air water interface, or it may be **supersaturated,** if it is being produced in the ecosystem faster than it is being released from solution across the interface. The concentration of important gases may vary from widely in any ecosystem, both horizontally and vertically.

The saturation level of any gas in water depends on several variables, most notably temperature, salinity, the concentration of the gas in the atmosphere, and its relative solubility in water. The greater the concentration of a gas in the atmosphere, the greater its concentration in the water will tend to be, depending on its relative solubility in water.

Table : Comparison between equilibrium concentrations of important gases in the atmosphere and in water (**Clapham, Jr.** 1973)

Gas	Atmospheric concentration	Saturation in water
Oxygen	210 cc./1·(21%)	7 cc./1·(32·9%)
Nitrogen	780 cc./1·(78%)	14 cc./1·(65·7%)
Carbon dioxide	0·3 c.c./1·(0·03%)	0·3 cc./1·(1·4%)

1. Oxygen : One of the most critical factor in an aquatic environment is the amount of oxygen in the water because most living organisms (excepting anaerobic forms) require this gas for respiration. In contrast to atmosphere, the oxygen becomes limitting factor for aquatic animals as the saturation concentration of oxygen in water is governed by temperature and salinity. As is evident in accompanying table, the lower the temperature, the greater the oxygen-retaining capacity of water, wether it is fresh water or sea water.

Table : Comparison of the saturation concentration of oxygen in freshwater and salt water environments with varying temperatures.

Water	Temperature, °c	Saturatien point in milliliter per litre
Fresh water	0	10·27
Salt water	0	8·08
Fresh water	30	5·57
Salt water	30	4·52

In fresh water areas of any depth and in the salt water habitat, there are three recognizable zones with regard to oxygen concentration. A surface stratum, where the oxygen tends to be in equilibrium with the atmosphere above. Below this surface stratum of variable depth is an intermediate stratum where oxygen values fluctuate in accordance with existing factors. Respiration, decomposition of organic materials (stagnant ponds) and stream pollution all tend to reduce the amount of available oxygen, while photosynthetic activity will often balance or more than balance oxygen loss. The deepest layers of water will usually have a very low oxygen concentration in the deeper lakes and oceanic areas because the continual decomposition of organic debris, the respiration of organisms inhabiting these deeper waters, and the complete absence of photosynthetic activity in these lower strata will tend to deplete the oxygen concentration. The deep stratum is entirely dependent upon the slow transport of oxygen from the overlying intermediate layer.

Because oxygen is needed for the respiration of all heterotrophs, it tends to be taken out of solution continuously by these organisms. The only means by which it can enter the water are via solution at the air-water interface or through photosynthesis by aquatic plants. Oxygen is transferred to deeper water by diffusion or through circulation of the water. The rate of oxygen solution at the surface is highly variable, depending mainly on the turbulence of the water and the presence of waves spray and foam.

Some organisms (*e.g.*, aquatic beetles, true bugs, fresh water snails, larvae of mosquitoes, whales, seals, porpoises, alligator, crocodiles, etc.) are independent of the oxygen concentration in water because they move to the surface and obtain atmospheric oxygen. Ingenious devices such as air tubes or the ability to trap air bubbles in surface hairs or under wings cover are utilized by some of these forms to insure submersion for an interval of time. Some bacteria and animals (*e.g. Teredo, Mytilus edulis*, etc.) can live anaerobically by breaking down glucose, glycogen and other carbohydrates and obtain oxygen from this source.

2. **Nitrogen** : Nitrogen is significantly less soluble in water than oxygen. But because it constitutes 78 per cent of the atmosphere, it still accounts for about 65 per cent of the dissolved gases at equilibrium. It is fairly inert chemically and does not react with water, although some bacteria, fungi, blue-green algae, and so on, can use it to satisfy their nitrogen requirements, and other bacteria can produce it through reduction of nitrate under conditions of very low oxygen concentration.

3. **Carbon dioxide** ; The decomposition of organic matter and the respiratory activity of aquatic plants and animals produce carbon dioxide. This gas is one of the essential raw materials necessary for photosynthetic activity by green plants. Carbon dioxide combines chemically with water to produce carbonic acid (H_2CO_3), which influences the hydrogen ion concentration (pH) of water. Carbonic acid dissociate to produce hydrogen (H^+) and bicarbonate (HCO_3^-) ions. The bicarbonate radical may undergo further dissociation forming more hydrogen (H^+) and carbonate ($CO_3^{=}$), as represented in following reactions :

$$\underset{\text{atmospheric}}{CO_2 + H_2O} \xrightleftharpoons[\text{air-water interface}]{} \underset{\text{dissolved}}{CO_2 + H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons H^+ + \underset{\text{bicarbonate}}{HCO_3^-}$$

$$\downarrow\uparrow$$

$$\underset{\text{carbonate}}{2H^+ + CO_3^{=}}$$

The amount of free or uncombined carbon dioxide in water is of ecological importance : it governs the precipitation of calcium in the form of calcium carbonate (Ca CO_3). Calcium precipitates when temperatures and salinity are high and the amount of uncombined carbon dioxide is low. This means more carbonate (CO_3^-) is present to combine with the calcium cation (Ca^{++}). These conditions exist in shallow tropical waters, where evaporation is high. This raises the salinity and photosynthetic activity of plants and reduces the quantity of free carbon dioxide in water. The precipitation of calcium carbonate in tropical areas as the Bahamas explains the preponderance of thick calcareous shells of shallow water tropical molluscs, plankton and algae. In deep oceanic waters, temperatures are low and there are no photosynthetic plants, consequently, the carbon dioxide content of the water is high. Deep water fauna (molluscs, crustaceans) possess very fragile skeleton because the precipitation of calcium carbonate is minimum.

4. **Hydrogen sulfide :** The deeper layers of many bodies of water, including ponds, lakes, and some estuaries, may contain significant amounts of the toxic gas, hydrogen sulfide, which is released by decaying organic matter. If concentrations of the gas build up, all life but anaerobic bacteria excluded from the area (*e g.*, deeper strata of Black sea).

b. **Hydrogen ion concentration (pH) :** One property of natural waters is their acidity or alkalinity. About one water molecule in every 10,000,000 splits into two, producing a hydrogen ion (H^+) and a hydroxyl ion (OH^-) :

$$H_2O \rightleftharpoons H^+ + OH^-$$

In pure water, there are equal numbers of H^+ and OH^- ions, it therefore has a **neutral reaction.** Some natural waters, however, acquire an excess of H^+ and are **acidic**, while others, with an excess of OH^- are **alkaline**. For example, in fresh water habitats such as acid bogs, swamps and drainage streams carrying water from these areas are acidic, contain pH value as low as 1.4. Despite the high acidity, rich populations of acidophilic flora and fauna thrive under such conditions. On the other hand, certain lake waters may be quite alkaline, particularly in lime stone areas, where the pH may range from 10 to 12. Basophilic plants and animals are found in these areas. In a vast majority of fresh water localities pH value range between 5·5 and 8·5. Oceanic areas exhibit little change in pH value over vast areas because of the effective buffering action of anions such as HCO_3^- and $CO_3^=$. Surface waters of open ocean have pH values of 8·0 to 8·4, but deeper water is closer to neutrality (pH 7·4 to 7·9). There is often a wider range of pH values in shallow marine waters, estuaries and tide pools.

HARD AND FRESH WATERS

Water containing soluble salts of calcium and magnesium such as chlorides, sulphates and bicarbonates, is called **hard water.** The hardness of water may be of two types—**temporary hardness** and **permanent hardness.** Temporary hardness is caused by **dissolved calcium** bicarbonate or magnesium **bicarbonate. Temporary hard-**

water can be converted into soft water by boiling, as at higher temperatures soluble bicarbonates of calcium and magnesium are converted into insoluble carbonates of calcium and magnesium. Permanent hardness of water is caused by dissolved chlorides or sulphates of calcium and magnesium. This hardness cannot be removed by boiling and requires some specific chemical treatments.

THE HYDROLOGIC CYCLE

Water continuously circulates between the atmosphere and the earth's surface (lithosphere) in what is known as the **hydrologic cycle.** The energy for driving this cycle and thus ensuring a constant supply of fresh water on land comes from the sun. Solar heat evaporates water from the ocean which is the great reservoir of water. A lesser amount of water is also evaporated from the surface of the land and from plants, a process known as **evapotranspiration.** All these vaporized water forms clouds which moved by winds, may pass over land where they are cooled enough to precipitate the water as rain or snow. Some of the precipitated water soaks into ground, some runs off the surface into streams and goes directly back to the sea. The ground water is returned to the surface by springs, by pumps and by transpiration—the movement of water in plants from roots to leaves. Water inevitably ends up back in the sea, but it may become incorporated into the bodies of several different organisms, one after another, en route.

EFFECT OF FACTOR OF AQUATIC ENVIRONMENT ON AQUATIC ORGANISMS

The aquatic environment is subject to water movements ranging from small vertical circulations to strong currents. The streams have a unidirectional movement and in seas the movement is reversible. Many aquatic animals have accordingly taken to sedentary or sessile lives depending on water movements. Radial symmetry is a characteristic of such animals. Transformation from a sessile to a locomotive existence favours a bilateral symmetry. The water currents of water often abrade the inhabiting flora and fauna and varied modifications are encountered to withstand this abrasive action. Thick scales, strong shells and many attachment devices like the hold-fasts and suckers all are the results of this environmental stress. The ability to breathe air dissolved in water, at times even resorting to anaerobic existence, the modification of various senses to respond to stimuli characteristic of aquatic environments, the phenomenon of osmoregulation, and above all the phenomenon of external fertilization are other spectacular physiological adaptations to live in an exclusively aquatic medium.

RELATION OF ANIMALS TO MOISTURE

Water makes up a large proportion of the bodies of plants and animals, whether they live on land or in water. Active cytoplasm holds about 70—90 per cent of water. It has several important physiological properties. Animal obtain water (i) by drinking, (ii) by absorbing it through their skin from contact with some damp ground, (iii) directly from their food or (iv) from water produced by metabolism. The method of obtaining water and the relation to the supply of liquid water as well as resistance to the drying effects of the surrounding atmosphere are important in determining the distribution of animals. Different animals have evolved following adaptive features to live in drying atmospheres—

1. **Impervious skin** : The drier habitats (deserts, etc.) are invaded by only those animals which contain a thick impermeable body covering. Such integuments occur in many insects, birds and mammals. Some mammals like men, apes and horses lose much water (and salt) through sweat glands in heat regulation. Most rodents and some ruminants like antelope nearly or completely lack sweat glands. Moist skinned forms (most amphibians and earthworms), certain mites and softbodied insects are restricted to swamps, stream margins, moist soils and other similarly damp places.

2. **Internal lungs or tracheal system** : Mode of respiration has some correlation with water. Crustaceans, with their gills covered by a water-retaining carapace, carry with them a liquid environment for their gills. The scaly body covering of a fish may be practically impermeable to water and exchange of gases may be limited to gills and gut. Internal lungs, whether in pulmonate snails, land isopods, spiders or higher vertebrates (amphibians, reptiles, birds and mammals) together with the internal tracheal system of insects are water saving. Much water is lost by in breathing even in animals having internal lungs.

3. **Dry excretion :** A further water-saving device is the excretion of concentrated, relatively dry nitrogenous and faecal waste materials. Water-saving insects, reptiles and birds excrete nitrogenous waste as solid uric acid.

4. **Suspended animation** : Certain animals, usually with simpler organization, such as rotifers, nematodes, tardigrades, desert snails, etc., retain their vitality in long dry environment. Other forms (frogs, toads, etc.) **aestivate** during droughts and are active during moist season of the year.

5. **Migration** : Many birds and mammals of arid zones migrate when water becomes scarce or as a result of drought or for other reasons, the food supply is less.

6. **Water from food and from metabolism** : Most herbivores and carnivores live on the moisture obtained with food. Many insects utilize the high water contents of plants to meet their water requirements. In fact, most animals make use of water released during metabolism when fats and carbohydrates are broken and water is also produced by the oxidation of hydrogen or carbon in the body of the animal. The camel in the desert can go on for 11 or more days without drinking water since it can use water of metabolism obtained from the oxidation of the fat in its hump as well as water stored in special compartments in the stomach.

AQUATIC FLORA AND FAUNA

With a few exceptions, almost all the taxonomic classes of micro-organisms, plants and animals have their representatives in aquatic environment. Each of them possessing specific morphological and physiological adapatations to exploit its specific environment fully. They will be discussed in the following chapters.

SNOW AS HABITAT

Snow which is the solid state of liquid water, is an integral factor in the physical environment. It is important particularly in the higher latitudes and on the higher parts of mountains where snow cover may last through the year. Its significance is increased by the large amount of land surface in northern Eurasia and North America. Snow covers much of the available food for many animals and is a factor causing migration, both of birds and mammals, toward areas that are somewhat free from its direct influence. Certain mammals (rodents, etc.) tunnel through the snow near the underlying masses and get access of food and often protection from winter cold. In the Tundra, the non-hibernating lemmings (*Dicrostonyx*) breed during winter beneath the snow. Snow prevents the locomotion of mammals and of running birds, and animals with long feet only are well adapted for moving on snow cover.

CHAPTER 3

ABIOTIC ENVIRONMENTAL FACTORS

The distribution, abundance, growth and reproduction of the organisms comparising the individual members of species populations are controlled by certain **environmental factors.** These factors are of two basic sorts : **abiotic environmental factors**, which determine the interactions between the population and the abiotic environment and **biotic environmental factors**, which may refer to interactions between different populations or to instinctive control mechanisms that are internal to the population itself **(Clapham,1973)**. In previous chapter, a discussion has been made of three fundamental media, namely soil, water and air which provide necessary conditions for sustaining life and which act as abiotic factors. In the present chapter, all the remaining abiotic environmental factors will be discussed.

NATURE OF RESPONSE OF ORGANISMS TO ABIOTIC ENVIRONMENTAL FACTORS

Probably the first response of any organism to a change in the environment is physiological **(Kendeigh**, 1974). Different abiotic environmental factors influence organisms physiologically in various ways **(Fry**, 1947). These effects may be classified as follows :

1. **Lethal**—Causing death ; for instance, extreme heat or cold, lack of moisture, and so forth.
2. **Masking**—Modifying the effect of some other factor. Low relative humidity increases the rate of evaporation of moisture from body surfaces so that warm-blooded animals are able to survive at otherwise intolerably high air temperatures.
3. **Directive**—Producing an orienting response in relation to some environmental response so that the organism gets itself into favourable conditions.
4. **Controlling**—Influencing the rate at which some process functions, but not entering the reaction. Temperature, pressure, and viscosity, for instance, affect metabolism, secretion, and locomotion.

5. **Deficient** : Some abiotic environmental factors curtail an activity of an organism because some essential ingredient, such as salt, oxygen, or the like, is absent or at unfavourably low concentration.

Further, the same abiotic environmental factor may produce different effects at different times and under different conditions. Temperature may be lethal, if extreme ; masking, as when cold reduces the demand of cold-blooded organisms for food ; directive, by inducing a search for more favourable locations ; or controlling, as a modifier of the rate of metabolism.

ESSENTIAL ELEMENTS AND LIMITING FACTORS

The individual organisms of species population, in order to grow and multiply, must be supplied with certain essential materials. Of the hundred four (*i.e.*, 104) naturally occurring chemical elements on the earth, all living organisms are believed to utilize only 16 different chemical elements for their survival. These are called **essential elements**. Several other elements are needed in small quantities by some species. They are summarized in following table :

Table : Essential elements (Clapham, 1973).

Macronutrients : Elements used in relatively large quantities.	**Micronutrients : Elements generally needed in relatively small quantities.**	**Micronutrients : Element needed by certain species in relatively small quautities.**
Carbon	Iron	Sodium
Hydrogen	Manganese	Vanadlum
Oxygen	Boron	Cobalt
Nitrogen	Molybdenum	Iodine
Phosphorus	Copper	Selenium
Calcium	Zinc	Silicon
Magnesium	Chlorine	Fluorine
Sulphur		Barium

Some of these tabulated elements are used in relatively large quantities as the fundamental building blocks of organic tissues and are called **macronutrients**. Others, the **micronutrients**, are used in much smaller quantities. The micronutrients are also known as **trace elements**. For instance, a crop such as corn will remove over 45 kg. of nitrogen per acre from the soil but only 10—15 g. of boron. In addition to the nutrients required by all species, some organisms have special nutrient requirements.

THE LIEBIG-BLACKMAN LAW OF LIMITING FACTORS

An organism is seldom, if ever, exposed solely to the effect of a single factor in its environment. On the contrary, an organism is subjected to the simultaneous action of all factors in its immediate surroundings. However, some factors exert more influence than do others, and the attempt to evaluate their relative roles had led to the development of the law of the minimum by the German biochemist **Justus Liebig** in 1840.

Liebig while investigating the relationship between the available amounts of essential elements and plant growth, discovered that crop yield was frequently limited by elements other than those utilized in the largest quantity. Freely translated, a part of his statement on his experimental results is that "*growth is dependent on the amount of food stuff that is presented in minimum quantity*." This statement has come to be known as **Liebig's law of minimum**. It is now usually incorporated with a **law of limiting factors** developed by a British physiologist **F. F. Blackman** (1905), who at the beginning of this century investigated the factors affecting the rate of photosynthesis. He listed five factors involved in controlling the rate of photosynthesis : amount of CO_2 available, amount of H_2O available, intensity of solar radiation, amount of chlorophyll present, and temperature of the chloroplast. Blackman discovered that the rate of photosynthesis is governed by the level of the factor that is operating at a limiting intensity. Further work on limiting factors and substances has shown that a high level of one factor will modify the limiting effect of a second, a process described as **factor interaction**. The same principle of limiting factors applies well to animal functions.

Since the rate of a process may be controlled by too great an amount of a substance, such as heat, as well as by too small an amount, and since the presence or abundance of an organism may be limited by a variety of environmental factors, biotic as well as abiotic, and since the limiting effect may be due to two or more interacting factors rather than a single isolated one (**Shelford**, 1952), the law of minimum has been restated by **Taylor** (1934) in broad ecological terms, as follows—"*The functioning of an organism is controlled or limited by that essential environmental factor or combination of factors present in the least favourable amount. The factors may not be continuously effective but only at some critical period during the year or perhaps only during some critical year in a climatic cycle.*"

THRESHOLD AND RATE

Every environmental factor varies through a wider range of intensity than any single organism can tolerate characteristically, there is for each individual organism a lower and an upper limit in the range of an environmental factor between which it functions efficiently. For any one factor, different organisms find optimal conditions for existence at different points along the range, hence their segregation into different habitats.

The **thresold** is the minimum quantity of any factor that produces a precipiteableeffect on the organism. It may be the lowest temperature at which an animal remains active, the least amount of moisture in the soil that permits growth of a plant, the minimum intensity of light at which a photoreceptor is stimulated, and so forth. Above the threshold, the rate of a function increases more or less rapidly as the quantity of heat, moisture, light, or other environmental factor is increased, until a maximum rate is attained. Above the maximum, there is usually a decline in the rate of a process either because of deleteriouseffect produced, the interference of some other factor or exhaustion.

SHELFORD'S LAW OF TOLERATION

Organisms may be limited in their growth and their occurrence not only by too **little** of an element or too **low** an intensity of a factor but also by too **much** of the element or too **high** intensity of the factor. For example, carbon dioxide is necessary for the growth of all green plants, small increase in concentration of carbon dioxide in the atmosphere will, under certain circumstances, increase the rate of plant growth, but very considerable increases become toxic. Likewise, small additions of arsenic to the human diet actually have a tonic effect, further increase in the dosage, however, soon proves fatal.

The idea that factors could be limiting at their maximum as well as minimum quantities was incorporated in **law of toleration** formulated by **V. E. Shelford** in 1913. This law postulates that each ecological factor to which an organism responds has maximum and minimum limiting effects between which lies a range or gradient that is now known as the **limits of tolerance**.

Between the **lower** and **upper** limits of tolerance lies a broad middle sector of a gradient which is called the **zone of compatibility**, the **zone of tolerance**, the **biokinetic zone** or the **zone of capacity adaptation**. The region at either end of the zone of compatibility is called the **lethal zone** or the **zone of resistance** or **zone of intolerance**. The zone of compatibility too includes a broad **range of optimum** and narrow **zones of physiological stresses** in between **the** range of optimum and lethal **zones**.

Upper and **lower limits of tolerance** are intensity levels **of a** factor at which only **half of the** organisms can survive. **These**

limits are sometimes difficult to determine, as for example with low temperature, organisms may pass into an inactive, dormant, or hibernating state from which they may again become functional when the temperature rises above a threshold. At high tempertures, there may be similar inactivation or aestivation before the lethal level is attained. Even without dormancy occurring, there are normally zones of physiological stress before the limits of tolerance are reached.

The species as a whole is limited in its activities more by conditions that produce physiological discomforts or stresses than it is by the limit of toleration themselves. Death verges on the limits of toleration, and the existence of the species would be seriously jeopardized if it were frequently exposed to these extreme conditions. Therefore, in retreat before conditions of physiological stress there is a margin of safety, and the species adjusts its activities so that limits of toleration are avoided. There is a variation in hardiness of individuals within a species, so that some hardy individuals find existence possible under conditions that disrupt other individuals. The population level of a species becomes reduced before the limits of its range are actually reached.

Further, species vary in their limits of tolerance to the same factor. For example, the Atlantic salmon spends most of its adult life in the sea, but goes annually into fresh water streams to breed. Most other marine fishes are killed quickly when placed in freshwater, as are freshwater fishes when placed in salt water. The following terms are used to indicate the relative extent to which organisms can tolerate variations in environmental factors. The prefix *steno*- means that the species, population, or individual has a narrow range of tolerance and the prefix *eury*- indicates that it has a wide range.

Table : Terminology for ranges of certain abiotic environmental factors.

Stenothermal — Eurythermal	Pertaining to temperature
Stenohaline — Euryhaline	Pertaining to salinity
Stenohydric — Euryhydric	Pertaining to water
Stenophagic — Euryphagic	Pertaining to food
Stenobathic — Eurybathic	Pertaining to depth
Stenoecious — Euryecious	Pertaining to niche or habitat selection

Moreover, a plant or animal may have a wide range of tolerance for one factor in the environment, but a relatively narrow range of tolerance for another condition. Thus, we find that some species of freshwater fishes are eurythermal but they are stenohaline.

TYPES OF ABIOTIC ENVIRONMENTAL FACTORS

The abiotic environmental factors can be classified into two basic classes namely **physical abiotic factors** including **temperature,** quantity and spectral quality of **light**, depth of water (*i.e.*, **pressure**), **geomagnetism, gravity, wind** and **precipitation** ; and **chemical abiotic factors** which include such factors as **nutrient availability** and **pH.**

TEMPERATURE

Temperature is one of the essential and obvious changeable environmental factors. It penetrates into every region of the biosphere and profoundly influences all forms of life by exerting its action through increasing or decreasing some of the vital activities of organism, like behaviour, metabolism, reproduction, ontogenetic development (*viz.,* embryogenesis and blastogenesis) and death. Temperature is a universal influence and is frequently a limiting factor for the growth or distribution of animals and plants. Normal life activities go on smoothly at a specific **temperature or at a specific range of temperatures.** This is called the **optimum temperature** or the optimum range of temperature. Organisms react to any rise or fall of the optimum temperature range and biotic communities more often encounter alterations only due to extremes of temperature (*viz.*, **minimum** or **maximum** temperatures). The interaction of temperature with certain other abiotic environmental factors such as humadity, etc., cause into many other climatic changes which influence the living organisms in one way or another.

NATURE OF TEMPERATURE

Temperature is a measure of the intensity of **heat** in terms of a standarized unit, and is commonly expressed as degrees on either the **Fahrenheit** or **Celsius scale.** Heat is a form of energy, and as such is necessary for the very existence of life. Heat may be received or lost by animals as molecular vibrations transmitted from one part of an environment to another by radiation, convection, or conduction. It may be received as radiant energy, of course largely from the sun. Heat may be produced by mechanical work as in Hawk moth, the heat is generated by vibrating the wings before take-off ; or by chemical reactions.

HEAT BUDGET

The temperature at the earth's surface is governed by the brightness of the sun ; the constancy of brighthess of sun has remained virtually unchanged for about 3 billion years. In fact, average terrestrial temperatures now probably do not differ radically from those at the earth's beginning (**Schwarzschild**, 1967). The total amount of heat entering the biosphere from the sun must balance the amount lost per unit time if temperatures are to remain unchanged, since the flow of geothermal heat from the interior of the earth is small by comparison and probably has been negligible for at least the past 500 million years. The estimate of this energy flow is referred to as the **heat budget (Vernberg** and **Vernberg,** 1970). Heat budget have been projected for the total surface of the earth as well as for special environments.

TEMPERATURE FLUCTUATIONS IN DIFFERENT ENVIRONMENTS

Environmental temperatures fluctuate both daily and seasonally. Different environments such as fresh water, marine and terrestrial environments, are subject to varied reponses to fluctuating temperatures. Temperature fluctuations are comparatively less in the aquatic environment than in the terrestrial environment. The increase in depth of aquatic medium often increases the temperature fluctuations. There exists a distinct difference in the response of living organisms of the freshwater and sea to temperature fluctuations because of the presence of dissolved salts in sea water. The minimum temperature in the sea is —3° C, while in freshwater ponds it never goes below 0°C. The maximum temperature of ocean generally goes upto 36°C, but in shallow pools of fresh water and tide pools of littoral zone, temperature may go higher. In deeper bodies of water, heating and cooling are restricted to the surface strata. But the deeper layers also get a lot of heat as a result of what is usually termed **vertical circulation**, where in, due to circulatory movement of water, surface waters are brought to the deeper regions, and vice versa. Studies on the vertical changes of temperature have led to the hypothetical classification of the freshwater media into three strata. The superficial layer of freshwater is constantly stirred by wind and is called **epilimnion**. It is the layer of warmer

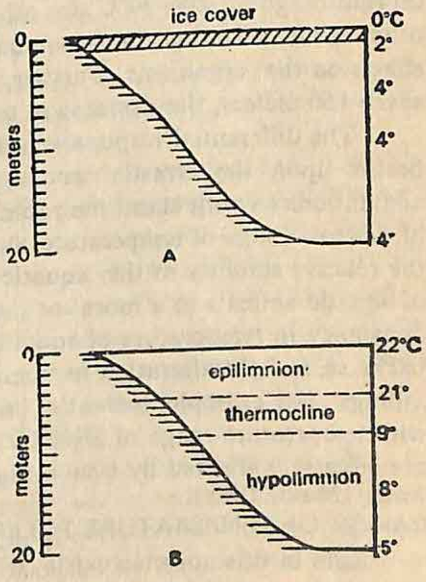

Fig. 3·1. Thermal stratification of a deep lake of the temperate region. A-during winter, B-during summer.

water and its temperature may rise upto 27°C during summers. The stagnant water of the bottom constitutes the **hypolimnion**. The hypolimnion has temperature of 5°C only. In between epilimnion and hypolimnion occurs an itermediate zone called **thermocline** or **metalimnion**, which has rapid vertical temperature changes. During winter, the temperature of epilimnion of a freshwater lake becomes 0°C and the lake becomes ice covered. The process of differentiation of fresh-water habitat into these three strata is called **thermal stratification.**

In the terrestrial environment the seasonal and daily fluctuations in temperature are varied and marked. The lowest temperature recorded for any land mass is —70°C (Siberia in 1947). Higher temperatures may likewise go often 85°C as in certain deserts at noon. However, the water in hot springs and geysers may approach 100°C, and even higher temperatures occur sporadically in the very special situations presented by volcanic areas. In Rajasthan the highest temperature exceeds 50°C. On land, diurnal variations of temperature are quite staggering. The fluctuation between day and night temperatures may be 17°C as in ordinary land masses or 40°C as in deserts. The Thar Desert of South Rajasthan (India) shows a diurnal range of 20—30°C for all seasons. Difference in latitudes often causes variation in the annual temperature cycles with visible effects on the organisms. Further, with the increased altitude for every 150 meters, the decrease in temperature of 1°C takes place.

The differential responses of land and sea to the temperature, bestow upon the terrestial and aquatic organisms certain special adaptations to with stand the rapid changes of temperature. Because of, narrow range of temperature fluctuations in the aquatic media, the relative stability of the aquatic media has led to the adaptation of aquatic animals to a more or less constant temperature. But this constancy in temperature of aquatic media has its certain own drawbacks as, a slight alteration in temperature often brings about mass killings. For example, torrential insects habitually inhabiting waters with temperature range of 2—4°C at altitudes of 1000—1400 meters are adversely affected by even a slight increase in the temperature of water (**Mani**, 1968).

RANGE OF TEMPERATURE TOLERANCE

Life in this universe exists within a range of —200 to 100°C. Though normal life persists within narrow temperature limits of about —10 to +50°C. Individual species survive in a smaller range and are active within even narrower limits. Many nematodes, rotifers and tradigrades have shown to withstand cooling to —272°C without ill effects. Larvae of chironomids and certain other Diptera have been found to thrive at temperatures near 55°C. Praying mantis is reported to live in bare grounds at a temperature of 62°C in deserts. Some algae and bacteria are reported to live in hot springs at 88°C. Non-photosynthetic bacteria inhabiting hot springs can actively grow at temperatures greater than 90°C (**Bott** and **Brock**, 1969). On the other hand, some arctic algae can complete their life cycles in places where the temperatures barely rise above 0°C. Further, the eggs of the acanthocephalan *Macracanthorhyhnchus hirudinaceus* have been known to withstand temperatures from —10 to —45°C for about 140 days, and desiccation at temperatures up to 39°C for a period of 265 days.

The organisms (microbes, plants and animals) which can tolerate very large fluctuations in temperature are called **eurythermal organisms.** For example, cyclops, toad, wall lizard, grass snake, man, etc., are the eurythermal animals. The organisms which can tolerate only a small variation in temperature are termed **stenothermal organisms**. The common stenothermal animals are fishes, snails, coral reefs, etc. In organisms all metabolic processes necessary for life start at a certain **minimum temperature** and increase with rise in temperature until they reach the maximum level at a temperature called **optimum temperature**. Further rise in temperature beyond optimum brings about decrease in metabolic rate, until it ceases at a temperature called **maximum temperature**.

Thus the favourable temperature range for any particular species is determined by the prevailing temperature at which normal physiological activities of the animals take place, as in the distribution of the rotifer *Keratella procura* (**Nayar**, 1970). This rotifer species is known to appear in the ponds of Pilani, Rajasthan (India), when the temperature is below 24°C and to disappear when it rises above 24°C, the frequency of distribution reaching a peak during months of October to March, with the fall in temperature.

POIKILOTHERMS AND HOMOTHERMS

An animals response to wide ranges in temperature is influenced by its physiology. All invertebrates, lower chordates (hemichordates, urochordates and cephalochordates), cyclostomes, fishes, amphibians and reptiles have no internal mechanism for temperature regulation, and their body temperatures vary with surrounding environmental temperatures. Such animals are called **cold blooded, poikilothermal** or **poikilothermic** organisms. The temperature range that a poikilothermic animal tolerates can be correlated closely with the environmental **temperatures** normally encountered in nature : tropical animals can not withstand low temperatures ; polar animals can not withstand high temperature ; temperate-zone animals survive a wide temperature range. Many poikilothermic animals show a rather precise discrimination of temperature. If the temperature decreases or increases appreciably, these animals may tolerate and adjust to change, may avoid the change by seeking a less exposed environment or may become inactive. Some animals respond by becoming dormant during periods of extreme temperatures. Such dormancy is called **estivation** at high temperature and **hibernation** at low temperatures. For example, most poikilotherms become inactive when the temperature of their surroundings goes below 8°C or rises to 42°C.

A few exceptional poikilotherms, especially insects, certain amphibians and reptiles, exercise a degree of thermo-regulation by either physiological or behavioural mechanisms. For example, Hawk moths can rise the temperature of their flight muscle to 32°—36°C by vibrating the wings before take-off and gregarious butterfly larvae may raise their temperature 1½—2°C when clustered together. Locust hoppers may increase their temperature 10°C by basking sideways in the sun. Ants move their larvae to warm or cool places within the nest and bees maintain temperatures within their hives between 13° and 25°C by fanning with their wings to evaporate water droplets when it is too hot, or releasing body heat through increased metabolic activity, when too cold.

When temperature drops, lizards bask in the sun to achieve the desired body temperature ; once this thermal level is attained, they will divide their time between sun and shade to maintain it. Poikilotherms such as desert dwellers that live in environments where the temperature is apt to be very high are often nocturnal and thus avoid the highest temperatures of the day. Some poikilotherms, both vertebrates and invertebrates, lower their body temperatures slightly by evaporative cooling. In frogs and reptiles, evaporative cooling can occur through the skin or via the respiratory tract by panting (**Warburg, 1967**). Among the invertebrates, evaporative cooling has been reported in tropical intertidal-zone animals (**Lewis, 1963**).

In contrast to poikilotherms, birds and mammals can, within limits, maintain constant body temperatures, regardless of temperature variations of air and water. Such animals are termed **warm blooded** or **homeothermal**. Their life processes are adjusted to function at the animal's normal temperature, averaging a little less than 38°C in mammals and 3 to 4° higher in birds. If its temperature control fails, the animal dies. The homeothermic animals are able to maintain the constancy of body temperature by a combination of several factors: (1) a thermo-regulating centre in the brain ; (2) insulation ; (3) a peripheral vascular response to ambient temperature ; and (4) metabolic compensation.

Among these factors, **insulation** is highly important particularly in enabling large arctic animals to withstand very low temperature. If the temperature is lowered, the oxygen consumption rate of tropical mammals increases, whereas that of arctic mammals remains basal. This response pattern is due to differences in insulation ; some arctic animals are fur-insulated, whereas others are insulated with a layer of blubber. Many small animals, however, are **not** well insulated and must seek heat retention by other means, often by huddling together.

Homeothermic animals living in very hot environments can not tolerate greatly elevated body temperatures and they utilize methods that facilitate heat transfer to the environment, including an increased peripheral blood flow and surface cooling by sweating or panting. Birds may accomplish this by rearranging their plumage so that more skin is exposed. There is however, no reduction in metabolic rate. Animals subjected to high temperature may exhibit diurnal patterns of behaviour—that is, they may reduce locomotor activity during the heat of the day or may move into the shade to avoid direct sunlight.

Various species shift between homeothermy and poikilothermy and are known as **heterotherms (Ananthakrishanan** and **Viswanathan,** 1976). These include animals such as the pigmy mouse and the little pocket mouse, which respond to temperature extremes by estivating or hibernating, and others such as the humming bird, which experience a nocturnal drop in temperature.

Plants too can be divided into the following three categories on the basis of their heat tolerating capacity : **megatherms, microtherms** and **mesotherms.** Megatherm plants occur in warm habitat (*e.g.*, desert vegetation). Microtherm plants occur in cold habitat, (*e.g.*, plants of high altitudes). Mesotherm plants are the plants of the habitat which is neither very hot not very cold (*e.g.*, aquatic plants).

FACTORS OR VARIABLES AFFECTING ORGANISMAL RESPONSE TO TEMPERATURE

The response of an organism to temperature is affected by a number of factors such as **thermal history**, **genetic differences**, **diet**, **size**, **stage in life cycle**, **sex**, **moulting**, **parasitism**, **hormones**, etc.

1. Generally, animals found in warmer environments can withstand higher temperatures than animals from colder situations. It is also generally true that animals from colder environments tolerate lower

temperatures better than those from the warmer climates. These differences between warm-climate and cold-climate populations may reflect basic genetic differences or may be phenotypic expressions resulting from different thermal histories. 2. The thermal resistance of a species may be closely identified with the genetic composition of the parent stock, as illustrated by hybrid development in two anuran species, *Bufo valliceps* and *B. luetkeni* (**Ballinger** and **McKinney**, 1966). The lower lethal temperature for development of *B. valliceps* is 18°C ; for *B. luetkeni*, 22°C. In their hybrids, the lower lethal limit is found to be in between that of the two parents at 19·5°C. 3. In some animals a relationship between the total intake of food and resistance to thermal stress has been demonstrated. Some species are more sensitive to elevated temperatures when they are starved for even short periods of time. Goldfish showed increased resistance to high temperature when placed on a high fat diet (**Hoar** and **Cottle**, 1952). 4. The size of animal body is found to have some correlation with thermal lethal limits of animals. In some species, the smaller animals are more resistant to higher temperatures than the larger ones ; in some species the reverse is noted, and in other species size is not an apparent variable. Further, some smaller animals die faster at low temperatures than do larger animals of the same species, but at higher temperatures body size is not a factor. 5. Many species of animals have exceedingly complex life cycles during which the larval stages are not only morphologically dissimilar from the adult but also occupy different ecological niches. In the wharf crab *Sesarma cinereum*, thermal requirements of the planktonic zoeal stages are different from those of adults because these larvae are limited a smaller temperature range than are the adults. 6. The female sex is found to be more tolerant than males to the temperature fluctuations. 7. Among certain invertebrates, such as, in some crabs moulting adversely affected heat resistance, but had no effect on other species. 8. Mud-flat snails, *Nassarius obsoleta*, which are heavily infected with trematode larvae (*i.e.*, parasites) can not withstand high temperatures like the non-parasitized snails. 9. Hormones have been shown to influence cold and warm resistance as well as acclimation (*viz.*, temperature adaptation) to temperature, especially in mammals and a few other invertebrates.

EFFECT OF TEMPERATURE ON PLANTS AND ANIMALS

Temperature has been found to affect the living organisms in various ways, for example, it has significant role on the cells, morphology, physiology, behaviour, growth, ontogenetic development and distribution of plants and animals. Some of well-studied effects of temperature on living organisms are following :

1. **Temperature and cell :** The minimum and maximum temperatures have lethal effects on the cells and their components. If too cold, cell proteins may be destroyed as ice forms, or as water is lost and electrolytes become concentrated in the cells ; heat coagulates proteins (**Lewis** and **Taylor**, 1967).

2. **Temperature and metabolism :** Most of metabolic activities of microbes, plants and animals are regulated by varied kinds of enzymes and enzymes in turn are influenced by temperature, consequently increase in temperature, upto a certain limit, brings about increased enzymatic activity, resulting in an increased rate of metabolism. For instance, the activity of liver arginase enzyme upon arginine amino acid, is found to increase gradually and gradually, with the simultaneous increase in the temperature from 17°C to 48°C. But an increase in temperature beyond 48°C is found to have an adverse effect on the metabolic rate of this enzymatic activity which retards rapidly.

In plants, the absorption rate is retarded at low temperature. Photosynthesis operates over a wide range of temperature. Most algae require lower temperature range for photosynthesis than the higher plants. The rate of respiration in plants, however, increases with the rise of temperature, but beyond the optimum limit high temperature decreases the respiration rate. The rate of respiration becomes doubled (like in animals) at the increase of 10°C above the optimum temperature, provided other factors are favourable (**Vant Hoff's law**). However, optimum temperature for photosynthesis is lower than that for respiration (**Smith**, 1974).

3. **Temperature and reproduction** : The maturation of gonads, gametogenesis and liberation of gametes takes place at a specific temperature which varies from species to species. For example, some species breed uniformly throughout the year, some only in summer or in winter, while some species have two breeding periods, one in spring and other in fall. Thus, temperature determines the breeding seasons of most organisms.

Temperature also affects fecundity of animals. **Fecundity** of an animal is defined as its reproductive capacity, *i.e.*, the total number of young ones given birth during the life time of the animal. For example, females of the insect, acridid *Chrotogonus trachypterus* became sexually mature at 30°C and 35°C than at 25°C, and the highest number of eggs per female was laid at temperatures of 30°C. The number of eggs decreased from 243 to 190 when the temperature was raised to 30—35°C (**Grewal** and **Atwal**, 1968). Likewise, in grass-hopper species—*Melanoplus sanguinipes* and *Camnula pellucida* when reared at 32°C produce 20—30 times as many eggs than those reared at 22°C (see **Ananthakrishnan** and **Viswanathan,** 1976). On the other hand, the fecundity of certain insects such as cotton stem weevil (*Pempherulus affinis*) was found to decline with an increase in temperature beyond 32·8°C (**Ayyar** and **Margabandhu,** 1941).

4. **Temperature and sex ratio :** In certain animals the environmental temperature determines the sex ratio of the species. For example, the sex ratio of the copepod *Macrocyclops albidu* is found to be temperature dependent. As the temperature rises there is a significant increase in number of males. Similarly in plague flea, *Xenopsylla cheopis*, males outnumbered females on rats, on days when the mean temperature remains in between 21-25°C. But the position becomes reverse on more cooler days.

5. **Temperature and ontogenetic development :** Temperature influences the speed and success of development of poikilothermic animals. In general complete development of eggs and larvae is more rapid in warm temperatures. Trout eggs, for example, develop four times faster at 15°C than at 5°C. The insect, chironomid fly *Metriocnemus hirticollis,* requires 26 days at 20°C for the development of a full generation, 94 days at 10°C, 153 days at 6·5°C, and 243 days at 20°C, (**Andrewartha** and **Birch,** 1954). However, the seeds of many plants will not germinate and the eggs and pupae of some insects will not hatch or develop normally until chilled. Brook trout grow best at 13°C to 16°C, but the eggs develop best at 8°C.

6. **Temperature and growth** : The growth rates of different animals and plants is also influenced by temperature. For example, the adult trout do not feed much and do not grow until the water is warmer than 10°C. Likewise, in the oyster *Ostraea virginica,* the length of the body increases from 1·4 mm to 10·8 mm when temperature is increased from 10°C to 20°C. Sea urchin *Echinus esculentus* shows maximum size in warmer waters. Corals flourish well in those waters which contain water below 21°C.

7. **Temperature and colouration** : The size and colouration of animals are subject to influence by temperature. In warm humid climates many animals like insects, birds and mammals bear darker pigmentation than the races of some species found in cool and dry climates. This phenomenon is known as **Gloger's rule**. In the frog *Hyla* and the horned toad *Phrynosoma*, low temperatures have been known to induce darkening. Some prawn (crustacean invertebrates) turn light coloured with increasing temperature. The walking stick

Carausius has been known to became black at 15°C and brown at 25°C.

8. Temperature and morphology : Temperature also affects the absolute size of an animal and the relative properties of various body parts (**Bergman's rule**). Birds and mammals, for example attain a greater body size when they are in cold regions than in warm regions, and colder regions harbour larger species. But poikilotherms tend to be smaller in colder regions. Body size has played a significant role in adaptation to low temperature because it has influenced the rate of heat loss. According to **Brown** and **Lee** (1969), larger wood rats have a selective advantage in cold climates, apparently because their surface to air ratio and greater insulation permit them to conserve metabolic heat. For opposite reasons small-sized animals are favoured in deserts.

Further, the extremities of organism like tail, ears and legs of mammals often appear to be shorter in colder climate (**Allen's rule**). Mice reared at 31° to 33·5°C have longer tails than those of the same strain reared at 15·5° to 20°C. Moreover. the races of birds with relatively narrower and more acuminate wings tend to occur in colder regions, while those in warmer climates tend to be broader (**Rensch's rule**). Temperature also influences on the morphology of certain fishes and is found to have some relation with the number of vertebrae (**Jordon's rule**). Cod which hatches off New Foundland at a temperature between 4° and 8°C has 58 vertebrae, while that hatches East of Nantucket at a temperature between 10° and 11°C has 54 vertebrae.

9. Temperature and cyclomorphosis : The relation between seasonal changes of temperature and body form is manifested in a remarkable phenomenon termed **cyclomorphosis** exhibited by certain cladocerans like *Daphnia* during the warm months of summer. These crustaceans show a striking variation in the size of their helmet or head projection between the winter and summer months (**Coker, 1931**). The helmet develops on the *Daphnia* head in spring, it attains its maximum size in summer and disappears altogether in winter to provide usual round shape to the head. Such a kind of cyclomorphosis in the terms of size of the helmet is clearly showing a corelation to the degree of warmth of different seasons. These prolongations of the helmet have been interpreted as an adaptation aiding floatation since the buoyancy of winter becomes reduced as the temperature increases (the **buoyancy hypothesis**). According to other interpretation (*viz*., **stability hypothesis**), the helmet acts like the rudder and gives greater stability to the animal. Besides temperature, such structural polymorphism can be caused by other environmental factors including the food.

10. Temperature and animal behaviour : Temperature generally influences the behavioural pattern of animals. In temperate waters the influence of temperature on the behaviour of wood borers is profound. For example, in the winter months in general, both *Martesia* and *Teredo* occur in smaller numbers in comparison with *Bankia campanulata* whose intensity of attack is maximum during the winter months. Further, the advantage gained by certain cold blooded animals through thermotaxis or orientation towards a source of heat are quite interesting. Ticks locate their warm blood hosts by a turning reaction to the heat of their bodies. Certain snakes such as rattle snake, copper heads, pit vipers are able to detect mammals and birds by their body heat which remains slightly warmer than the surroundings. Even in the dark these snakes strike on their prey with an unnerving accuracy, due to the heat radiation coming from the prey. The arrival of cold weather in temperate zones causes the snakes to coil up and huddle together.

11. Temperature and animal distribution : Because the optimum temperature for the completion of the several stages of the life cycle of many organisms varies, temperature imposes a restriction on the distribution of species. Generally the range of many species is limited by the lowest critical temperature in the most vulnerable stage of its life cycle, usually, the reproductive stages. Although the Atlantic lobster will live in water with a temperature range of 0° to 17°C, it will breed only in water warmer than 11°C. The lobster may live and grow in colder water but a breeding population never becomes established there. Not only temperature effect on breeding in the geographical distribution but also temperature effects on survivality (*i.e.*, lethal effect of temperature), feeding, and other biological activities are responsible in geographic distribution of animals. As noted earlier in this chapter, the animals from colder geographic regions are generally less heat tolerant and more cold tolerant than those animals from warmer regions ; for example, members of *Aurelia*, a jelly fish from Nova Scotia die at a water temperature of 29-30°C, while *Aurelia* from Florida can tolerate temperatures upto 38.5°C. Thus, lethal limit of temperature may regulate the range of distribution of *Aurelia*.

Generally, the distribution of shallow-water marine species can be assigned to four types of zonation. In the first type, northward distribution is dependent on thermal lethal limits during the winter months, and southern distribution is dependent on summer temperature limits. In a second type, the thermal limits required for population determine the north to south distribution. In the third type of zonation, the thermal requirements for repopulation determine the poleward habitat in summer, and the maximum temperature determines the equatorward survival area. Finally, the minimum temperature for survival determines the poleward limit in winter and temperatures limiting repopulation determine the southward range. Terrestrial invertebrates, particularly arthropods generally are distributed in all thermal environments where life is found. Many arthropods that have invaded the colder areas have one stage in their life cycle which is very resistant to cold, enabling them to overwinter until warmer weather returns (**Salt**, 1964). Birds and mammals are also adapted to live in nearly all thermal environments. The distribution of amphibians and reptiles, however, is limited to the relatively warmer thermal climates. **Hock** (1964) has listed three factors that limit the invasion of reptiles into cold environments: the daily ambient temperature must be high enough to allow activity, the daily ambient temperature must be high enough and long enough to allow breeding and to allow adults and young to acquire food for "overwintering" and there must be adequate sites for hibernation.

12. Temperature and moisture : The differential heating of the atmosphere resulting from temperature variation over the earth's surface produces a number of ecological effects, including local and trade winds and hurricanes and other storms, but more importantly it determines the distribution of precipitation.

THERMAL ADAPTATIONS OF PLANTS AND ANIMALS

Most animals and plants of different ecological habitats have developed various sorts of thermal adaptations during the course of evolution to overcome the harmful effects of extremes of temperature some of the significant thermal adaptations of plant and animals are following :

1. Formation of heat resistant spores, cysts, seeds, etc. : Some of the animals and plants produce heat resistant cysts, eggs, pupae, spores and seeds which can tolerate extremes of temperatures. *Amoeba* in encysted conditions, can tolerate temperature below 0°C, Similarly *rye* seeds remain active even at 0°C and can germinate at that temperature. As an adaptation against frost the starch of plants changes to fats or oils in the autum. The fatty oils depress the freezing point and thus increase the power of resistance in plants against frost. Many leaves, that grow in the coldest lands, store fats. Pentosans mucilage and pectic substances which have high moisture retaining power are abundant in many plants. They decrease the danger of plants from desiccation during extremes of heat and save them from death.

2. **Removal of water from tissue :** Dried seeds, spores and cysts avoid freezing because there remains no liquid in them that can freeze. Due to removal of water from seeds, the cold resistance of seeds of certain plants increase upto the extent that their exposure for 3 weeks to 190°C, does not diminish their germinating capacity.

3. **Dormancy :** Dormancy includes two already discussed phenomena namely **hibernation** and **aestivation**. During both kinds of dormancies metabolic rate becomes reduced, body temperature becomes low and heart beat rate is also reduced.

4. **Thermal migrations :** Thermal migrations occur only in animals. The journeys taken by animals that enable them to escape from extremely hot or cold situations are referred to as **thermal migrations**. For example, desert animals move to shaded places to avoid burning heat of noon and some animals like desert reptiles and snakes become nocturnal to avoid heat of the day. The frogs, toads, other amphibians, turtles, etc., make short trips into or out of water (or moist places) and this provides desired cooling and warming to the animal.

LIGHT AND RADIATIONS

The radiant energy from the sun is the basic requirement for the existence of life on the earth. This source of energy is of fundamental importance to the photosynthetic production of food by plants and as mentioned previously, the heat budget of the world is dependent on solar radiation. Although we generally, think only in terms of visible light, the sun emits other radiations of different wavelengths-cosmic rays, gamma rays, X-rays, ultraviolet rays, infra-red rays, heat waves, spark discharges, radar waves, radio waves, slow electro-magnetic waves. Biologists have been primarily interested in only three regions near the centre of the electromagnetic spectrum—(1) the infra-red, (2) the visible light and (3) ultraviolet regions. The **infra-red wavelengths**, which are the longest of these three, are not visible to the human eye ; they contribute to the warmth of the earth at the high altitudes in the terrestrial atmosphere. **Visible light**, is only a small fraction of the radiation spectrum and contains the frequency of wavelengths ranges from 390 to 700 millimicrons (mμ). It is made up of a series of colours ranging from violet through indigo, blue, green, yellow, orange and red, all constituting the **visible spectrum**. Light energy, thus, reaches the earth as electro-magnetic waves of solar radiation with tremandous velocity and supplies most of the warmth the earth receives from the sun and also supplies the main source of energy which is utilized in photosynthesis of plants, oriented and rhythmic behaviour of animals, bioluminescence, periodicities of occurrence and periods of inactivity. Unlike temperature, light is a non-lethal ecological factor and it has a specific direction in its flow. The wavelength of **ultraviolet light** from the sun is shorter than that of visible light, and it produces the upper levels of the earth known as the ionosphere.

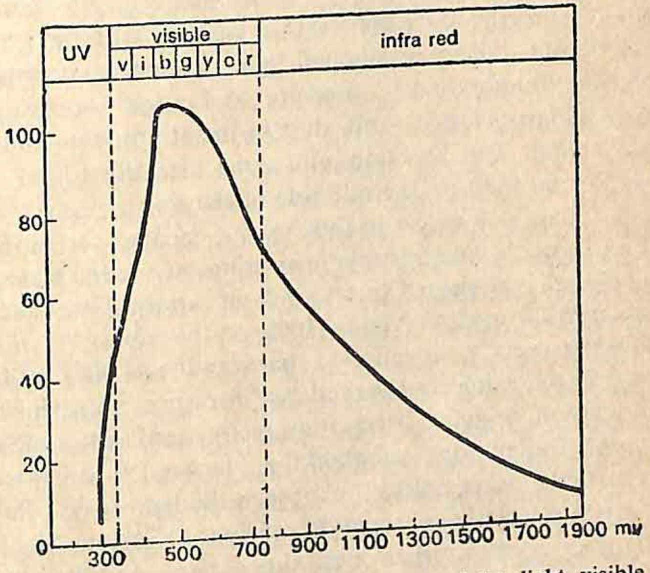

Fig. 3·2. Spectral distribution of ultraviolet light, visible light and infra-red radiation at the earths surface.

LIGHT RECEPTORS OF ANIMALS

Since animals depend on light for orientation, diurnal migrations and synchrony of rhythmic activities light reception probably is the most important sensory modality in the exploration of the environment. It is not surprising, therefore, that receptors for light are common to almost all animals ; in those with better developed photo-receptors, light greatly influence behaviour. Light receptors may be well-defined organs such as the vertebrate eye, the compound eyes of crustacea and insects, the simple eyes or ocelli of other arthropods and invertebrates, and the dermal light receptors.

LIGHT VARIATIONS IN DIFFERENT ENVIRONMENTS

Light energy varies with different media. The transparency of air and water is important in regulating the amount and quantity of light that may be available in particular habitats. For example, the intensity of light reaching the earth's surface varies with the angle of incidence, degree of latitude and altitude, season, time of day, amount absorbed and dispersed by atmosphere and a number of climatic and topographical factors such as fog, clouds suspended water drops, dust particles, etc., when the angle of incidence is smaller, light rays have to travel by a longer distance through the atmosphere, which resulting into relative reduction in intensity. Likewise, sun's altitude changes due to differences in latitude, changes in the season and in the time of day. When sun remains overhead, the intensity of sunlight over the earth's surface will be greatest. At higher latitudes the intensity of light becomes correspondingly reduced. The illumination or intensity of daylight is greatly diminished by moisture, clouds, and dust in the atmosphere and also by forest vegetation. The direction and slope also affect light intensity. There will be no light on the one side of the slope.

The light which enters in the aquatic media, comes from sun by passing through the atmosphere existing above the water surface and hence, that is subjected to all kinds of atmospheric factors like that of terrestrial media. About 10% of the sunlight which falls over the water surface, is reflected back and rest 90% of that pass downward in the water and is modified in respect to intensity, spectral composition, angular distribution (refraction) and time distribution. The phytoplankton, zooplankton, suspended organic and inorganic particles either reflect or absorb the light rays. Further, in water there is a selective absorption of light at various depths. The longer light rays are absorbed near the surface and in general the shortest light rays penetrate deepest. Thus, long heat and infra-red rays are absorbed in the upper layers of water (about 4 metres) ; red and orange rays are completely absorbed upto the depth of 20 metres; yellow rays penetrate upto 50 metres and green and blue rays penetrate upto 80 to 100 metres deep. Violet and ultraviolet rays penetrate beyond 100 metres and no light ray penetrates beyond 200 metres depth. Depending upon the penetration of light, oceans are divided into **euphotic zone** (upto 50 metres depth), **disphotic zone** (upto 80 to 200 metres depth) and **aphotic zone** (below 200 metres of depth). In the ocean, algae are distributed according to length of light rays that their colours are best suited to absorb and to utilize : green algae live in the intertidal zone, brown algae decend somewhat deeper and red algae are characteristic of deep oceanic water.

EFFECT OF LIGHT ON THE PLANTS

Light energy influences almost all the aspects of plant life directly or indirectly. Thus, it controls plant's structure, form shape, physiology, growth, reproduction, development, local distribution, etc. On the basis of light factor certain ecologists have classified plants into **sciophytes, shade loving,** or **photophobic plants** which have best growth under lower intensities of light, and **heliophytes** or **photophilous plants** which have best growth in full sunlight. The light factor affects following aspects of plant life :

A. **Direct effects of light on plants :** Light affects directly following aspects of plant life—1. It is an essential factor in the formation of **chlorophyll** pigment in chlorophyllous plants. 2. It has a very strong influence on the number and position of **chloroplasts.** The upper part of the leaf which receives full sunshine has larger number of chloroplasts which are arranged in line with the direction of light. In leaves of plants which grow under shade, chloroplasts are very few in number and are arranged at right angle to the light rays, thus increasing the surface of light absorption. 3. Light has its most significant role in **photosynthesis**. During photosynthesis, the green plants which are the "primary producers" of an ecosystem, synthesize their carbohydrate food from water and CO_2 in the presence of sunlight. Thus, during photosynthesis, the solar radiant energy is transformed into the chemical or molecular energy which remains stored in chemical bonds of carbohydrates and this chemical energy is utilized by other chlorophyllous and non-chloroyhyllous parts of plants, all animals, bacteria and viruses in their different life activities. The rate of photosynthesis is greater intermittant light than in the continuous light. At high intensity of light a photo-oxidation of chlorophylls and other enzymes takes place, which consequently reduce the rate of synthesis of carbohydrates and proteins. However, high intensity of light results in the formation of **anthocyanin** pigments. It is for this reason alpine plants have beautifully coloured flowers. 4. Light inhibits the production of **auxins** or **growth hormones** as a result of which it influence the shape and sizes of plants. Plants grown in insufficient light or in the total darkness, produce maximum amount of growth hormones, as a result of which they are elongated with weak pale yellow stems with very few branches. 5. Light also influence certain chemical compounds of plants which effect the differentiation of specialized tissues and organs. 6. Leaf structure too is influenced by the intensity of light. The thickness of leaf increases with the increasing light intensity. 7. The development of flowers, fruits and seeds is greatly affected by light intensity. Diffused light or reduced light promotes the development of vegetative structures and causes delicacy. For example, vegetative crops like turnips, carrots, potato and beets give highest yield in regions with high percentage of cloudy days. Intense light favours the development of flowers, fruits and seeds. 8. Duration of light is also very important. Actual duration or length of the day **(photoperiod)** is a significant factor in the growth and flowering of a wide variety of plants. The controlling effect of **photoperiod** is called **photoperiodicity**. According to the response to length of photoperiods, the plants have been classified into following three groups :

(a) **Long day plants** : Which bloom when the light duration is more than 12 hours per day, *e.g.*, radish, potato, spinach, etc.

(b) **Short day plants** : Which bloom when the light duration is less than 12 hours per day, *e.g.*, cereals, tobacco, cosmos, dahelia, etc.

(c) **Day neutral plants** : Which show little response to length of day light, *e.g.*, tomato plant.

9. Light also affects the movement in some plants. The effect of sunlight on the plant movement is called **heliotropism** or **phototropism**. The stems elongate towards light (positive phototropism) and the roots are negatively phototropic. The leaves grow transversely to the path of light. 10. The seeds when moist are very sensitive to light. In some cases the **germination of seeds** is retarded in light. 11. Light is an important factor in the distribution of plants. Some plants grow in full sunlight, while others prefer to grow in the shades.

B. **Indirect effect of light on plants** : Light affects opening and closing of stomata, influences the permeability of plasma membrane and has heating effect. All these in turn effect **transpiration** which in turn effects **absorption** of water. Light affects **respiration** of plants indirectly, as in the presence of light the respiratory substrates are synthesized. In many plants the respiratory rate increase with the increase in the light intensity (*e.g.*, *Canna*, *Nerium*, *Bougainvillea*). However, in certain plants respiration rates decreased slightly in intense light.

EFFECTS OF LIGHT ON ANIMALS

Light affects divergent aspects of animal's life. It influences cellular metabolism, growth, pigmentation, locomotion, reproduction, ontogenetic development, and also controls the periodicity and biological clocks of animals. Some of its significant effects can be discussed as follows :

1. Effect of light on protoplasm : Though the bodies of most animals remain protected by some sort of body covering which save animal tissues from the lethal effects of solar radiations. But, sometimes sun rays penetrate such covers and cause excitation, activation, ionization and heating of protoplasm of different body cells. Ultraviolet rays are known to cause mutational changes in the DNA of various organisms.

2. **Effect of light on metabolism** : The metabolic rate of different animals is greatly influenced by light. The increased intensity of light results in an increase in enzyme activty, general metabolic rate and solubility of salts and minerals in the protoplasm. Solubility of gases however, decreases at high light intensity. Cave dwelling animals are found to be sluggish in their habits and to contain slow rate of metabolism.

3. **Effect of light on pigmentation** : Light influences pigmentation in animals. Cave animals lack skin pigments. If they are kept out of darkness for a long time, they regain skin pigmentation. The darkly pigmented skins of human inhabitants of the tropics also indicate the effect of sunlight on skin pigmentation. The skin pigments synthesis is dependent on sunlight. Light also determines the characteristic patterns of pigments of different animals which serve the animals in sexual dimorphism and protective colouration. Animals that dwell in the depths of the ocean where the environment is monotone, though pigmented do not show patterns in their colouration.

4. **Effect of light on animal movements** : The influence of light on the movement of animals is evident in lower animals. Oriented locomotory movements towards and away from a source of light is called **phototaxis**. Positively phototactic animals such as *Euglena*, *Ranatra*, etc., move towards the source of light, while, negatively phototactic animals such as planarians, earthworms, slugs, copepodes, siphonophores, etc., move away from the source of light.

The light directed growth mechanisms are called **phototropisms** which occur in sessile animals. Phototropisms also includes responsive movement of some body part of some active animal to the light stimulus, such as the movement of flagellum of *Euglena*, towards light and movements of polyps of many coelenterates.

The velocity or speed of the movement of certain animals is also regulated by light. It has been observed that animals when responding to light reduce their velocity of movement and these movements which are non-direction are called **photokinesis**. Photokinesis may be a change in linear velocity (**rheokinesis**) or in the direction of turning (**klinokinesis**). During photokinesis when only a part of the body of an animal deviates aways from the source of light, the reaction is termed **photoklinokinesis**. Larvae of *Musca domestica* show such movements. When animals are confronted with two lights of equal brightness they move towards or away to a position that is distance between the two lights. This is termed **phototropotaxis.** Attraction of males towards the flash of the female is called **telotaxis.** Movements of animals at a constant angle towards the source of **light is to light compass reaction** or **celestial orientation.**

Celestial orientation : Some organisms, particularly arthropods, birds and fish, utilize their time sense as an aid to find their way from one area to another. To orient themselves, the animals use the sun, moon, or stars as a compass. To do this, they utilize both their biological clock and observations on the azimuthal position of the sun in relation to an established direction. The **azimuth** is the angle between a fixed line on the earth's surface and a projection of the sun's direction on the surface. Using the sun as a reference point involves some problems for animals because the sun moves. The target angle changes throughout the day. But animals which use the sun as a reference, correct their orientation somehow. Such celestial orientation has been observed in fishes, turtles, lizards, most birds, and such invertebrates as ants, bees, wolf spiders and sand hoppers.

5. **Photoperiodism and biological clocks :** Regularly occurring daily cycles of light (day) and darkness (night) have been known to exert a profound influence on the behaviour and metabolism of many organims. Underlying such environmental rhythms of light and darkness are the movements of the earth relative to the sun and the moon. The earth's rotation on its axis results in alternation of night and day. The tilt of the earth's axis, along with the annual revolution around the sun produce the seasons. The response of different organisms to environmental rhythms of light and darkness is termed **photoperiodism.** Each daily cycle inclusive of a period of illumination followed by a period of darkness is called the **photoperiod.** The term **photophase** and **scatophase** are sometimes used to denote the period of light and the period of darkness respectively. Different animals have evolved different morphological, physiological, behavioural and ecological adaptations during the course of their evolution to varying photoperiods, which provide them with environmental information regarding the intensities of natural light.

(a) Daily responses : Circadian rhythms : Life evolved under the influence of daily and seasonal environmental changes, so it is natural that plants and animals would have some rhythm or pattern to their lives that would synchronize them with fluctuations in the environment. For years biologists have been intrigued over the means by which organisms kept their activities in rhythm with the 24 hour day, including such phenomena as the daily pattern of leaf and petal movement in plants, the sleep and wakefulness of animals and the emergence of insects from pupal cases. At one time biologists thought that these rhythmicities were entirely **exogenous**, that is, the organisms responded only to external stimuli such as light intensity, humidity, temperature and tides. But now it is well investigated that most animals possess **internal** or **endogenous** rhythms in synchrony with the external or exogenous rhythms of the environment, due to which they remain able to measure the length of day. The internal or endogenous rhythms are approximately of 24 hours duration, while the exogenous or environmental rhythms are exactly of 24 hours duration. The term **circadian** (from the Latin *circa*, about, and *dies*, daily) has been used to denote these daily rhythms. The period of circadian rhythm, the number of hours from the beginning of activity one day to the beginning of activity on the next, is called **free running**. Photoperiod plays a role in providing time signals, for adjustments of the animals concerned to these daily rhythms. Circadian rhythms apparently are internally driven or endogenous, are affected little by temperature changes, are insensitive to a great variety of chemical inhibitors, and are innate, not learned from or imprinted upon the organisms by the environment.

The innate character of circadian rhythm is demonstrated by several animals. When *Drosophila* are kept under constant conditions from the larval stage , they will still emerge from pupae with a regular circadian rhythm. Eggs of chicken and lizards kept under constant conditions produce animals that later show regular circadian cycles. The circadian rhythms has been observed in zooplanktons, polychaete annelids, many insects (Lepidoptera, Diptera, Hymenoptera, Neuroptera, Coleoptera, Orthoptera, Odonata, etc.), most birds, and certain mammals.

The possession of a circadian rhythm that can be entertained to environmental rhythms provides plants and animals with a **biological clock**, which is an integral part of cellular structure and is a chemosensory system very receptive to the environmental stimuli. The biological clocks of different animals run or oscillate continuously and environment does not initiate or stop their function. At most certain environmental stimuli may serve to regulate the functions of biological clocks.

(b) Annual rhythms : Circannual rhythms : Solary day, lunar day, tidal rhythms, monthly and annual rhythms are also of common occurrence among animals. Endogenous annual cycles or circannual rhythms have been known in many animals like ground squirrels, warblers and other birds, some crayfishes and slugs. The circannual rhythms are of adaptive value for timing seasonal events and specify the levels of migratory activity that are just sufficient for the birds to reach the vicinity of their species - specific winter quarters. The circannual rhythms also effects gonadial activities, reproductive cycles, metamorphosis, and adaptations to cold (development of fur and feather coats of animals during winter), and so on.

6. Effect of light on reproduction : In many animals (*e.g.*, birds) light is necessary for the activation of gonads and in initiating annual breeding activities. The gonads of birds are found to become active with increased illumination during summer and to regress during shorter periods of illumination in winter.

7. Effect of light on development : Light in some cases (*e g.*, *Salmon* larvae) accelerates development, where as, in other (*e.g.*, *Mytilus* larvae) it retards it.

Further, occasionally the output of sunlight is increased by the development of **sunspots**. As a result of this excess energy is radiated to space and this naturally increases the output of solar energy near the earth. A direct consequence of this is the greater evaporation of water which results in cloud formation to prevent more exposure to sunshine and thus to equalize temperature and modifying climate.

PRESSURE

Barometric pressure have little effect on organisms. An amoeba in motion in spite of stopping under slight pressure is insensitive to increased pressure on the whole body. But in an ocean, pressure is an unavoidable ecological factor. In general, an increase of hydrostatic pressure is inversely proportional to the pace of life. While as altitude increases atmospheric pressure decreases. Pressure influences solubility, ionic dissociation and surface tension and water is slightly compressible with increased pressures. Since incompressible bodies are influenced very little by increased pressure, they will sink in the sea, and apparently this factor is important in food settling to the deep-water benthic fauna.

GEOMAGNETISM AND GRAVITY

The earth may be described as a magnetized sphere in which magnetic axis is inclined about 11 degrees relative to the geographical axis. Geomagnetism and gravity are involved in the adaptation of an organism to its environment. Like light, temperature and pressure they are omnipresent ecological factors with which life steadily interacts. The living systems of planarians and snails have been found to be extraordinarily sensitive to magnetic fields of earth.

MASS MOVEMENTS IN AIR AND WATER

The air and water media are always in a state of flux. Constant currents of water and air (wind) influences the inhabiting organisms. The currents of water besides being an influencing factor of the concentration of gases and salts also directly act as limiting factors. Corresponding differences in structure are met with in stream inhabiting organisms. On land, air currents or wind forms are important limiting factor. Birds confine themselves to shelter on days when the wind is strong. The transportation of microbes, plants and animals by hurricanes to hitherto unoccupied land may change the nature of the whole biotic community.

TIDE

Tides affecting biota comprise a regular rhytmic rise and fall oceanic water twice a day, as a result of which changes occur in the shore line. Tides are regulated by moon. At new moon and full moon the attraction of the sun and moon on tides reinforce each other and cause tides to rise higher and fall down without changing the mean sea level. This is called **spring tide**. During the first and last quarters of the moon the forces oppose each other and the daily fluctuations are much smaller due to neutral effects of the forces and this is the **neap tide.** Covering and uncovering of the tidal zone directly affect the biota by covering them with water and exposing them to air and sunlight, respectively.

CHEMICAL ABIOTIC FACTORS

Oxygen is primary source of life. It becomes a limiting factor in its complete absence, but, due to its abundance it very rarely becomes a limiting factor. High CO_2 concentrations become limiting to animals. pH value often becomes a limiting factor in different habitats. Non-availability of certain micronutrients such as calcium carbonate becomes a limiting factor for land snails (**calciphilic species**). *Sellana radiata*, the common limpet of Madras has been known to react to the changes of sea water concentrations of various ions. For example, it respond to very small dilutions of the sodium chloride of 0.0001 per cent.

MICROCLIMATE

Uptill now, we have discussed the influence of different ecological media and of different abiotic environmental factors on the living organisms. All these factors form the **macroclimate** which is measured by the meteorologists But the climate in which animals actually live is very much different from the gross environmental conditions.

This immediate environment of animal is called **effective climate or microclimate** and relates to such of the habitats of animals as those living in the soil within crevices of barks of trees, inside sheaths of grasses, within burrows, in ants nests, beneath logs of wood or rock, within caves, on vegetation in sand dunes, within plant galls and a variety of habitats which are occupied by endoparasites. Woodlice, centipedes and millipedes, for example, remain restricted to dark microhabitats during the daytime to prevent rapid water loss for transpiration. When temperature falls and relative humidity increases at night, these animals emerge of the daytime microhabitats.

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CHAPTER 4

BIOTIC ENVIRONMENTAL FACTORS

No organism under natural conditions is divorced from all other living things. Generally a number of different species will exert either a direct or indirect effect on a particular individual because the vital processes of growth, nutrition, and reproduction depend upon the coactions or interaction of other members within the species (**intraspecific interactions** or **coactions**) or between members of heterogeneous groups (**interspecific interactions** or **coactions**). These coactions may either be beneficial to the participants—**cooperation,** or harmful—**disoperation**. Interspecific cooperations include mutualism, commensalism, and many of the interrelations that establish the community as a dynamic unit. Coactions that are harmful, to at least one of the participants, include amensalism, parasitism, predation, and competition. Many of these coactions act to regulate density or, along with climate, cause fluctuations or even more drastic changes in number of individuals from time to time, and so constitute **biotic environmental factors**. Other biotic factors are ethics (established behavioural interrelations between individuals, characteristic of a species) and other inherent properties of members of a species.

INTERSPECIFIC BIOTIC FACTORS

Interspecific biotic factors consist of several different types of interactions or coactions between species. They may result in a relative increase, parity, or decrease in the population size (or density) in relation to what that level would have been in the absence of the interaction. The interaction may act throughtout the entire range of one or both of the species or it may be restricted to a portion of their range. The basic classes or types of interspecific interactions are of following types :

Table : Basic types of interspecific interactions. (Odum, 1971)

Types of interaction	Effect on population growth and survival of two populations, A and B				General results of interaction
	when not interacting		when interacting		
	A	B	A	B	
1. Neutralism (A and B independent)	0	0	0	0	Neither population affect the other
2. Competition (A and B competition)	0	0	—	—	Population most affected and eliminated from niche
3. Mutualism (A and B partners or symbionts)	—	—	+	+	Interaction obligatory for both
4. Protocoperation (A and B cooperates)	0	0	+	+	Interaction favourable to both, but not obligatory
5 Commensalism (A commensal ; B Host)	—	0	+	0	Obligatory for A ; B not affected
6. Ammensalism (A amensal, B inhibitor or antibiotic)	0	0	—	0	A inhabited ; B not affected
7. Parasitism (A parasite ; B host)	—	0	+	—	Obligatory for A ; B inhibited
8. Predation (A predator ; B prey					

+ Population growth increased
— Population growth decreased
0 Population growth not affected

1. NEUTRALISM

Neutralism is the most common type of interspecific interaction. Neither population directly affects the other. If there are interactions, they are of a more subtle and indirect type. The mere presence of the two species should not directly affect the population level of either. For example, robins (birds) and squirrels living in a forest present a good example of neutralism, as, neither serves as food for the other, neither has any direct interaction say that both may inhabit the same tree yet both are clearly part of the forest community.

2. COMPETITION

Competition refers to the type of interaction in which two individuals or species vie for a limited amount of food, water, nesting space, cover, mates or other resources. When these materials are in more than adequate supply for the demands of those organisms seeking them competition does not occur ; When they are inadequate to satisfy the needs of all the organisms seeking them, the weakest, least adapted, or least aggressive individuals are often forced to do without going elsewhere, or become locally extinct. This phenomenon is generally known as the **competitive exclusion principle of Hardin** (1960). Though, competition may result in death for some competitors, but this is from fighting or being deprived of food or space rather than being killed for food as in predation or by disease as in extreme parasitism.

Types of competition : Competition may be either direct or indirect. It is **direct** where there is active antagonism, struggle, or combat between individuals ; **indirect**, when one individual or species monopolizes a resource or renders a habitat unfavourable to the establishment of other organisms having similar requirements. Direct competition or **interference**, is evident in the fighting of bull seals for large harems and of grouse for a better position in the social hierarchy ; in chasing and colour display by fish and birds for defense of territories ; in the singing and calling of frogs, birds and some mammals as invitations for mates ; and in the excretion of chemicals that affect the behaviour or health of other organism (**allelochemistry**). Indirect competition, or **exploitation** is common among plants when certain species monopolize the water and nutrient resources of the soil or available light so that competing species cannot maintain themselves. Once an area is well saturated with established individuals to seek homes elsewhere, even in less favourable situations, than to intrude (see **Kendeigh**, 1974). Trout, for example grow more rapidly to large size when other trout species and forage species are low or absent (**Cooper**, 1959). Further, two species of butterflies, the monarch and the queen monarch of florida, are attracted to the flowers of the same milkweed plant, upon which they both feed and lay eggs and on which the larvae feed. The non-migratory queen monarchs, however, avoid some species of milkweed that the monarch utilize. But after the monarchs have flown northward, the queen monarchs oviposit on this milkweed. Thus the disappearance of the monarchs coincides with a population increase in the queen monarchs.

Degree of competition : Competition is usually keenest between individuals of the same species, **intraspecific competition**, because they have identical requirements for food, mates, and so on, and because they are more nearly equal in their structural, functional, and behavioural adaptation. **Interspecific competition** occurs where different species require in common at least some materials or condition. The severity of competition depends on the extent of similarity or overlap in the requirements of different individuals and the shortage of the supply in the habitat. It is generally the case that the more unlike the kinds of competing organisms, the less intense the competition. Yet birds compete with squirrels for acorns, nuts. and seeds ; insects and ungulates compete for food in grassland ; the bladderwort plant competes with small fish for entomastraca and other planktons.

The immediate test of success in competition is survival ; the ultimate test is leaving the largest number of established offspring.

Effects of competition on population : Competition has five important effects in the animal community : 1. Allelochemistry, establishment of social hierarchies. 2. Establishment of territories. 3. Regulation of population size. 4. Segregation of species into different niches, and 5. Speciation. The first three effects are chiefly intraspecific, while, last two effects are interspecific. In any case, competition for the resources of the ecosystem, both interspecific and intraspecific, is a prime means of population regulation. No population can exist at a higher density than can be maintained on the basis of the availability of needed resources as intraspecific and interspecific competition will remove those individuals that are less able to exploit the resources of the ecosystem (**Clapham, Jr**., 1973).

3. MUTUALISM

Mutualism is an obligatory interaction that is strongly beneficial to both species. The term **symbiosis** has often been applied to this relationship (*i.e.*, mutualism), but symbiosis properly refers to intimate association of two or more disimilar organisms, regardless of benefits or the lack of them and hence includes mutualism, commensalism and parasitism (see **Smith**, 1974). Mutualism may be **facultative**, when the species involved are capable of existence independent of one another, or **obligate**, when the relationship is imperative to the existence of one or both species.

Mutualism in plants is demonstrated in the associations of fungi and algae to form lichens, of nitrogen-fixing bacteria with the roots of legumes, and of fungal mycorrhizae with the roots of many flowering plants. Further, there are many intimate relations between plants and animals. Mutualism is evident in the presence of photosynthetic algal cells in the protective ectoderm of green hydra, and those associated with turbellarians, molluscs, annelids, bryozoans rotifers, protozoans and the egg capsules of salamanders. The algae give off oxygen, benefiting the animals, which in turn supply CO_2

and N_2 to the plants. Likewise, certain beetles, ants and termites cultivate fungi for food. Bacteria in the caeca and intestine of herbivorous birds and mammals aid in the digestion of cellulose. The cross pollination of flowers by the agency of insects and birds seeking nectar and pollen is of such great importance that many structural adaptations in both plants and animals fit the one to the other to ensure the success of the function. Moreover, birds and mammals are of great importance as agents of plant distribution. Seeds, fruits, even entire plants become attached to feathers or fur or ingested seeds are eaten and eliminated unharmed with the faeces.

Interspecific mutualism is nicely demonstrated by the flagellate protozoan, *Trichonympha* an obligate anaerobe in the gut of several species of wood-eating termites where it digest cellulose. *Trichonympha* also occurs in the alimentary canal of wood-eating roach *Cryptocercus*. The termite and roach reduce the wood to small fragements, passing them through the alimentary canal to hind gut, where the protozoans digest the cellulose, changing it into sugar. The host benefits the protozoa by removing harmful metabolic waste products and maintaining anaerobic conditions in the intestine.

4. PROTOCOOPERATION

Protocooperation is less extreme sort of interaction than mutualism in which the interaction is clearly beneficial to both species, allowing the equilibrium population levels of both to be higher than they otherwise would be. However, it is not obligatory for either species. Examples of protocooperation are many, including the relationship between water moccasins and large birds such as herons and ibises on several islands off the west coast of Florida. The birds nest in the lower branches of relatively unprotected trees, while the snakes congregate around the bases. This protect the bird from tree climbing predators such as racoons. In turn, the snake feed, in part, on fish dropped by the birds and the occasional baby birds that falls out of the nest (**Ehrenfeld,** 1970).

There is no clear demarcation between protocooperation and mutualism, as in many cases where a mutually beneficial relationship is obligatory for one species but not for the other. For instance, the nitrogen-fixing bacteria in the roots of legumes plant could not survive without the host plant. However, the host plant could probably survive without the bacteria.

5. COMMENSALISM

Commensalism defines the coaction in which two or mor species are mutually associated in activities centering on food an one species at least, derives benefit from the association while th other associates are neither benefited nor harmed. The concept of commensalism has been broadened in recent years, to apply to coactions other than those centering on food ; cover, support, protection, and locomotion are now frequently included (**Baer**, 1951 ; **Kendeigh**, 1974).

The **epiphytes** such as orchids "spanish moss" and" old man's beard" grow in the branches of trees, where they are near light ; their roots draw nourishment from the humid air. All these epiphytes depend upon the trees for support only. They manufacture their own food by photosynthesis. Likewise, ectocommensals or **epizoite** animals are associated with another animal for the purpose of anchorage and protection. Many small animals, for example, become attached to the outside of larger ones, such as the protozoans *Trichodina* and *Kerona* on *Hydra*, vorticellids (*Vorticella*, *Epistylis*) or various other aquatic organisms, branchiobdellid annelids on crayfish the barnacles, which attach themselves to the backs of whales and shells of horse-shoe crabs and so on. The remora fishes attach themselves to the bellies of sharks, swordfish, tunny, barracuda, or sea turtle by means of a dorsal fin highly modified into a suction disk on the top of the head. They are of small size and are not burdensome to the host. The host benefits the remora, however, for when the host feeds, the scraps of food floating back are swept up by the remora.

Commensals may also be internal. For example, many harmless protozoans occur in the intestinal tract of mammals, including man. The pea crab, *Pinnotheres*, lives as a commensal in the mantle cavity of certain sea mussels ; the crap steals food collected by the host mollusc but does little if any other known injury. The hermit crab normally lives inside gastropod shell. The pitcher of the pitcher plant found in bogs furnishes a breeding site or home for certain species of midge flies, mosquitoes, and tree toads. Many kinds of microorganisms, plants and animals (such as small crabs, shrimps, polychaets, ophiuroids, ascidians, etc.) live in the canal system of sponges.

The nest of one species often furnishes shelter and protection for other species as well. Ant nests may contain guest species of various other insects ; some birds place their nests close to wasps, bees or ants for the protection offered by these insects. Woodchuck burrows are used also by rabbits, skunks and racoons, especially in winter.

6. AMENSALISM

Contrasting with commensalism is **amensalism**, a situation in which one population definitly inhibits the other while remaining unaffected itself. By so modifying the environment, the organism improves its own chance of survival. Ammensalism commonly involves some type of chemical interaction, by which the organisms of one species affects the well-being and growth of individuals or the population biology of other, is called **allelochemic** (see, **Whittaker.** 1970, **Smith,** 1974; **Kendeigh,** 1974). The inhibitor substance may be inorganic chemicals such as acids or bases which are produced by pioneering organisms (inhibitor species) and which reduce the competition for nutrients, light, and space, between the amensal species and inhibitor species. The production of relatively simple organic toxins is another source of chemical inhibitors. These toxins inhibit seedling growth in the vicinity. This may affect succession of plant species, especially important in the early stages (**Muller** 1966). A third type of inhibitor chemical is the **antibiotic** potent antimicrobial agent. It is a substance produced by an organism, which, in low concentrations, can inhibit or kill the growth of another organism.

The majority of inhibiting chemical are produced as secondary substances by plants and released into the soil through the roots or leaf wash. The suppression of growth through the release of chemicals by a higher plant is known as **allelopathy.** For example, walnut tree produces a non-toxic substance, juglone (**Bode,** 1958) which is found in its leaves, fruits and other tissues. When the leaves or fruits fall on the ground, juglone is released to soil, where it is oxidized to a substance that inhibits the growth of certain under story species and garden plants such as heaths and broad-leafed herbes, and favours others such as bluegrass and blackberries.

Atibiotics produced by bacteria, fungi, actinomycetes, and lichens are widespread in nature and may be one of the reasons why bacteria pathogenic to man cannot multiply well in soils. A number of antibiotics such as penicillin, have been used extensively in human medicine.

Allelochemic effects are of great variety in both plants and animals : repellants, escape substances, supprssants, venoms, inductants, counteractants, attractants. signals, stimulants, autotoxins, autoinhibitors, and so on. **Pheromones** (ectohormones) are chemical messages between members of a species especially important in reproductive behaviour, social regulation and recognition, alarm and defense, territory or trail marking, food location, and so on. Many of these effects are beneficial to the individual, while others serve for competitive purposes (**Whittaker** and **Feeny,** 1971).

7. PARASITISM

Parasitism is a kind of harmful coactions (disoperation) between two species. It is the relation between two individuals wherin one individual called **parasite** receives benefit at the expense of other individual called **host**. Parasitism is mainly a food coaction, but the parasite derives shelter and protection from the host, as well. A parasite usually parasitize a host which is larger in body size than it. Further, a parasite does not ordinarily kill its host, at least not until the parasite has completed its reproductive cycle. However, a host may die due to some secondary infection or suffer from stunted growth, emaciation, or sterility. The balance between parasite and host is upset if the host produces antibodies or other substances which hamper normal development of the parasite. In general the parasite derives benefit from the relation while the host suffers harm. But this does not mean that all parasites are harmful. The former category constitutes the **pathogenic parasites.**

Classification of parasites—Parasites exhibit a tremandous diversity in ways and adaptations to exploit their hosts. The parasites may be **viral parasites** (*e.g.*, bacterial, plant and animal viruses), **microbial parasites** (*e.g.*, bacteria, protozoa, fungi, etc.), **phytoparasites** (*e.g.*, plant parasites) and **zooparasites** (*e.g.*, animal parasites such as platyhelminthes, nematodes, arthropodes, etc.) .They may parasitize microorganisms, plants and animals. They may occur on the outside of the host **(ectoparasites)** or live within the body of the host **(endoparasites).** The endoparasites usually live in the alimentary tract, body cavities, various organs or blood or other tissues of host. Ectoparasites may be parasitic only in the immature stages—the hairworm larvae, parasitic in aquatic insects ; only the adult parasitic—fleas, on birds and mammals ; or both larvae and adults may be parasitic—the blood sucking lice and flies, biting lice, mites, and ticks that occur on birds, mammals, and sometimes reptiles, and the monogenetic trematodes on fish. Similar relation occurs in endoparasites but in them usually all the stages of life are parasitic—entozoic amoebae, trichomonad flagellates, opalinid ciliates, sporozoans, pentastomids, nematodes, digenetic trematodes, acanthocephalons, cestodes, and some copepodes.

Further, endoparasites rely on various means of transport from one host to another so that their survival, range of distribution, and life cycle are unaffected. For the endoparasite, the interior of its host is its **microhabitat** and **microenvironment**, while the outside environment is the **macroenvironment**. The host acts as a buffer between the parasite and the outside environment changes in the microenvironment directly influence the parasite while alterations in the macroenvironment influence it directly. Thus, mutual adaptations and tolerance between the host and parasite are important factors facilitating successful transmission of endoparasites, and climatic fluctuations tend to alter the physiology of the parasite, host or vector. Mutual adaptation is the parasite's ability to establish and maintain itself in a favourable location within the host and exist in a proper form for sufficient length of time enabling subsequent transport to another host and continuation of species.

Animals may also be parasitic to plants. Nematodes infest the roots of plants. Wasps or gnats form galls on plants such as oaks, hickories, willows, roses, goldenrods, and asters. Mites stimulate formation of witches brooms in hackberry. A variety of insects the larvae of which are leaf miners, wood borers, cambium feeders, and fruit eaters should be included here.

Lastly, parasites may be **full-time** (or **permanent**) **parasites** or **part-time** (or **temporary**) **parasites**. Mosquitoes and bugs that suck the blood of their hosts are temporary parasites. Some temporary parasites spend only a part of their life cycle as parasites. For example, glochidium larva of *Anodonta* (fresh water mussel) attaches itself to the body of the fish by means of its hooks and penetrates inside the fish integument to remain burried there for several weeks and finally emerges out as the young mussel to lead an independent existence. Permanent parasites, however, spend their life completely on other organisms. The common examples of permanent parasites are—*Plasmodium*, *Entamoeba histolytica*, and other protozoan pathogens, different platyhelminthes, nematodes, arthropods, etc.

Parasitic adaptations—While studying parasitism as a biotic factor influencing the life and activities of parasites and hosts we often encounter manifold adaptations, both offensive and defensive, being developed by the host, as well as by the parasite. A endoparasite entering a host often meets with the antibodies or phagocytic cells produced by the host. The ectoparasites, and endopararsites have following parasitic adaptations :

1. In parasitic animals, a reduction of organs of special sense of nervous system, and of locomotory organs occur.

2. Most ectoparasites develop some clinging organs such as hooks, suckers, etc., to get attached with the body of their hosts. They also develop special piercing and sucking organs to suck the blood of animals or sap of plants. Certain blood-sucking ectoparasites such as leeches, blood-sucking mosquitoes, etc., contain certain anticoagulent enzymes in their salivary secretions.

3. Most endoparasites exhibit anaerobic respiration, high rate of reproduction, parthenogenesis, hermaphroditism, polyembryony, intermediate hosts and a complicated life-cycle (**Lapage**, 1951). Some endoparasites, such as tapeworm, have become so adapted to the host that they no longer require a digestive system. They simply absorb their food directly through their body wall. Further, parasites that live within the bodies of plants and animals possess cuticles or develop cysts resistant to the digestive enzymatic action of the host.

4. Many parasites pass their entire existence in a single host, others require one, two, even three intermediate hosts. It is of ecological significance that both primary and intermediate hosts of a parasite occur in the same habitat or community. Even then the hazards to successful passage from one host to another are so great and mortality so high that prodigious quantities of offspring are produced to ensure that at least a few individuals will complete the cycle.

5. Parasites are transferred from one host to another by active locomotion of the parasite itself ; by ingestion, as one animal sucks the blood of or eats another ; by ingestion as an animal takes in eggs, spores, or encysted stages of the parasite along with its food or drinking water ; as a result of bodily contact between hosts ; or by transportation from host by way of vectors. For example, the bacteria that cause tularemia in man are carried from rabbit to rabbit by ticks. Man contacts the disease when he handles infected rabbits but the incidence of infection is greatly reduced in the autum when cold weather forces the ticks (*i.e.*, the vectors of bacteria) to leave the rabbits and go into hibernation.

Host specificity of parasites : Certain parasites, such as copepodes, contain a wide range of hosts and they are ubiquitously present in various invertebrates and fishes. Most parasitic genera, however, are adapted to hosts of one phylum only. For example, each order of birds possesses its own particular species of tapeworms. This is true even when several order of birds live in the same habitats as do, for, instance, grebes, loons, herons, ducks, waders, flamingoes and cormorants (**Baer**, 1951). Species of flagellate protozoans that occur in termite alimentary canals are largely host—specific. Some species of gall wasps attack only one species of oak. Where a single species parasitizes two or more host species, the shape and structure of the gall formed around the egg and larva on both hosts is essentially similar. When several insects are found on the same oak, each kind of parasite produces its own characteristic gall form. The parasite-specific gall formation is found to be related with parasite-specific enzyme (**Kinsey**, 1930).

Certain parasites remain restricted to special habitats within the host. The roundworm lives near the duodenum of the digestive tract and soil nematodes live in the rootlets of plants. Biting lice remains restricted to the head or body regions of birds. Some zooparasitic nematode species are found throughout the body in connective tissue, but not in the gut ; some occur only in the digestive tract and associated organs ; certain species occur in the glandular crop of birds, but others only in the caecum ; many species occur exclusively in the lungs or in the frontal sinuses. Such fine restrictions of parasites to particular microenvironments—hosts or organs is a consequence of precise physiological and morphological adaptations that permit the parasite to survive and complete the life cycle only under very special conditions. Likewise, the life cycle of the parasite is often closely synchronized in time with that of its host (**Foster**, 1969).

Effects of parasite on the host : disease : Parasites may not cause immediate mortality but they cause damage to body structures, should it become excessive, may cause death. Because of these parasite caused anatomical damages, the finely adjusted balance of different vital processes of host's body become disturbed and host is said to be diseased. There are a number of causes of diseases. Parasites are one ; physiological stress, nutritional deficiency and poisoning are others. Some of common parasitic agents of disease and consequent mortality of animals are following :

1. Viruses are the potent agents of several disastrous diseases of plants and animals including man. For instance, some viruses are the agents of hoof and mouth disease in deer, spotted fever in rabbit, encephalitis and distemper in foxes.

2. Bacteria may produce localized inflamatory changes in tissue, enter the blood stream, or produce powerful poisons known as toxins. They cause a variety of diseases, notably tularemia, paratyphoid, and tuberculosis among birds and mammals, as well as other diseases in lower types of organisms.

3. Fungus spores of *Aspergillus* may be drawn into the lungs of ground-feeding birds, where they germinate and grow, causing **aspergillosis disease**. Fungus may also develop on the external surface of animals.

4. Protozoan parasites are especially important in the alimentary tract and in the blood. A sporozoan species of *Eimeria* damages the walls of the intestine in upland game birds and causes **coccidiosis disease** ; *Toxoplasma* becomes encysted in the brain of rodents ; *Leucocytozoon* is a common blood parasite of waterfowl and game birds.

5. Worm parasites, such as tapeworms, nematodes, and acanthocephalans may wander through the hosts body doing mechanical injury as well as destroying and consuming tissues. The host may respond by forming a fibrous capsule or cyst around an embedded parasite.

6. External parasites such as ticks, fleas, lice, mites, and flies do not commonly produce serious mortality by themselves, but they are often vectors transmitting protozoa, bacteria and viruses from one animal to another. Heavy infestations of external parasites, however lower the vitality or vigour of an animal and cause diseases of fur or feathers.

7. Nutritional deficiency in vitamins or minerals, or improper balance among carbohydrates, proteins, and fats may produce malformations, lack of vigour, even death.

8. Food poisoning, **botulism,** occurs when certain food become contaminated with the toxins released by the bacterium *Clostridium botulinum*. Many waterfoul are striken in some localities.

9. Physiological stress (**Selye**, 1955) is a term that has come to be applied to changes produced in the body non-specifically by many different agencies which, may accompany any disease. Effects of stress include loss of appetite and vigour, ache and pains, and loss of weight. Internally, physiological stress causes following abnormalities, such as, acute involution of the lymphatic organs, diminution of the blood eosinophils enlargement and increased secretory activity of the adrenal cortex, and a variety of changes in the chemical constitution of the blood and tissues.

10. Accidents, ageing, starvation, and so on, must also be included as important causes of mortality.

Organisms that produce disease generally fall into one or two categories. They are either present in the body at all times but not normally virulent, or they are normally absent but are virulent from the momment the host is infected by them. Further, a single attack, even a mild one of some diseases often confers a partial or complete **immunity** from further attacks of same disease. Like parasites, disease can reduce populations, exterminate them locally, or restrict the distribution of host. For example, smallpox, intentionally or unintentionally introduced nearly exterminated some tribes of North American Indians (*viz.*, Human populations). Malaria in southern Asia depressed population growth.

Social parasitism : Social parasitism describes the exploitation of one species by another, for various advantages. It is a kind of parasitism in which the parasite foists the rearing of its young into the host. Social parasitism in various stages of development is found among some higher vertebrates and insects. For example, there occurs a **egg parasitism** in two species of birds—old world cuckoos and the brown headed cowbirds of North America, both of which do not build nests of their own, rather they deposit their eggs in the nests of other species, abandoning eggs and young to the care of foster parents. One species of ant waylays foraging workers of another species and snatches away the food they are transporting or the robber species may deliberately rob another nest of food. Some species of ants make slaves of the workers of other species. Such kind of dependency of one species on another also occurs in other social insects such as termites, wasps and bees. Social insects are apparently the only animals other than man to have succeeded in domesticating other species, and of cultivating plants particularly fungi for food.

Parasitodism : Some Diptera and Hymenoptera deposit their eggs in the immature stages of other insects ; the larvae on hatching feed on the host until they are fully grown. In such type of parasitism in which host generally dies of the larval depredations before the larva emerges and the parasitoid larva generally lives in spite of the hosts death, is called **parasitodism**. It stands in between parastism and predation. The parasitoids may in turn be infested with **hyperparasitoids.** In the Chicago, *Samia cecropia*, a saturniid moth, suffers the destruction of nearly 23% of its cocoon by an ichneumonid parasitoid, *Spilocryptus extrematis*, which deposits an average of 33 eggs on the inside of each coccon or on the surface of larva. The host larva dies in a few hours after the parasitoid hatches and the ichneumonid larva moves about freely, feeding on the cuticle or burrowing into the tissues to drink the body fluids. *S. extrematis* is infested by another hyperparasitoid, *Aenoplex smithii* which causes about 13% destruction of *S. extrematis* cocoons. A chalcidid, *Dibrachys boucheanus*, fed both upon *S. extermatis* and as a tertiary parasitoid, upon *A. smithii*.

8. PREDATION

Predation is a form of disoperation, at least in point of immediate effects, since one animal kills another animal or plant for food. Like parasitism, predation is important in community dynamics but both differ in the point that a predator tends to be larger than its prey, and it catches its prey from without, while a parasite is smaller than its host and consume it from within (see **Clapham**, Jr., 1973).

COMPONENTS OF PREDATION

The main components of predation. are predators and prey. A successful **predator** has following characteristics :

1. The hunting ability of a predator remain well developed.

2. By their hunting activities predators can be regarded as specialized or generalized. **Specialized predators** are those adapted to hunt only a few species. They are forced to move when the vulnerability of a staple prey item drops to a point where the predator population cannot support itself. For example, Peale's falcon shows a marked preference for ducks and pheasants. Deer exhibit a pronounced preference for certain species of browse (**Klein**, 1970). **Genaralized predators**, not so restricted in diet, adjust to other food sources. The horned owl and buted hawk have a large range of collective prey available. Foxes can shift to a vegetable and carrion diet, should conditions require it.

3. Hunting ability and success of predator involve the development of a searching image on the part of the predator. Once it has secured a palatable item of prey, the predator finds it progressively easier to find others of the same kind.

4. Though a predator may have a strong preference for a particular prey, it can turn in the time of relative scarcity to an alternate, more abundant species that provides more profitable hunting. For example, if rodents are more abundant than rabbits and quail, foxes and hawks will concentrate on them instead of game animals.

5. Habitat preferences or overlapping territories can bring predator and prey into close contact, increasing prey risks. For example, predatory rainbow trout in Paul Lake, British Columbia, moves into the shoals when their prey, the red side shiner, are most heavily concentrated there.

6. Age, size, and strength of prey influence the direction that predation takes. Predator select food on the basis of size. Mountain lions, for example, avoid attacking large healthy elk, which they cannot successfully handle, and concentrate instead on deer and young or feeble elk (**Hornocker**, 1970).

7. Predators hunt only when it is necessary for them to procure food. The searching rate of predator is influenced by the

speed of the predator relative to the speed and escape reactions of the prey, to the distance at which predators first notice and attack the prey and to the proportion of attacks that result in successful capture.

Like the predators, the prey has its certain defensive specializations. The prey risk is determined by density of prey population, availability of food and protective cover (concealment place), movement, activity, habits, size, age, strength and escape reactions of prey.

Regulating effect of predation : It is commonly concluded that the predator—prey interaction causes a reduction in the prey population, it is deterimental in same fashion to the prey. This belief has led to extensive "predator control" efforts conducted in the name of wildlife conservation. But the coevolution of species within natural ecosystems has in fact led to a dynamic balance between the populations in a community, so that the population sizes of predator and prey species are inter-regulated by feed back mechanisms that effectively control the populatlon of both. As the models of **Lotka-Volterra** and **Nicholson-Bailey** stated, a predator that consistently destroyed more prey organisms than the prey population could stand would drive itself, as well as the prey, into extinction, because it would cut off its own food supply. Likewise, if the level of predation is too low, a prey population—whose evolutionary history has, after all, conditioned it to a normal level of losses to predation—may become too large, where upon it can destroy its food supply.

Ricker (1954) has recognized two kinds of predation—A and B. In type A predation, predators of any given abundance take a fixed number of prey species during the time they are in contact, usually enough to satiate themselves. The surplus prey escape. Trout feeding on an evening hatch of mayflies would come under this category. There is a functional response but no numerical response. Type B predation exists if predators of any given abundance take a fixed fraction of a prey species, as though the prey were captured at random encounters. In other words, the amount of prey eaten is proportional to the abundance of predator and the abundance of the prey. There is both a functional and a numerical response. Many vertebrates, however, do not follow the same functional and numerical response in relation to prey and predator. As predators take most or all the individuals of the prey species that are in excess of a certain minimum number, as determined by the carrying capacity of the habitat and social behaviour. The prey species compensates for its losses through increased litter and brood size and greater survival of young. For this reason this type of predation, Ricker's type C, is called **compensatory**. The population level at which predators no longer find it profitable to hunt the prey species has been called the "**threshold of security**" by **Errington** (1946). As prey numbers increase above this threshold, the surplus animals are no longer tolerated in the area, and become vulnerable to predation. Below the threshold of security, functional response of the predator is very low and numerical response is non-existent. Above the threshold, functional response is marked and numerical response could occur.

INTRASPECIFIC BIOTIC FACTORS

Besides interspecific interactions of biotic factors, there occur intraspecific interactions which operate along with other abiotic and biotic ecological factors in insuring the stability of animal populations. Some of the significant intraspecific biotic factors are following :

1. COLONIZATION

An early manifestation of intraspecific cooperation in the evolution of animals is the grouping of free-living protozoans to form **colonies**, and the further development of such colonies into multi-cellular metazoans that thereafter behave and respond as unit organisms. Whether the first gathering of protozoan cells to form colonies developed for better protection from some predator or environmental condition, improved utilization of food supplies, or more efficient reproduction, it is impossible to say (see **Kendeigh**, 1974). The colonial form, however, must have had survival value to persist.

Outcomes of colonization : During the course of evolution the colonization quickly led to **division of labour** between somatic and reproductive cells, as occurs in *Volvox*, and later to division of labour between somatic cells themselves, so that different cells or organs became specialized to serve the particular functions of digestion, respiration, circulation, excretion, and so on. Cooperation among cells, tissues, and organs gave greater metabolic efficiency to the whole individuals and resulted in evolution to the highest types of animals.

2. AGGREGATION

Aggregation refers to the tendency among animals to concentrate in numbers larger than found in normal distribution, and which congregate under various circumstances mostly by their own movements. Besides modifying the abiotic environment, more particularly the microclimate, aggregations bring about changes in the morphology, physiology and ethology of the aggregating members, there by acting as a very effective biotic factor. Aggregations of animals have some survival significance—as hundreds, sometimes thousands, of spotted lady beetles hibernate under leaves at the forest-edge. May-flies, midges, and mosquitoes swarm for mating purposes. Millions of bats roost together in large caves. The migratory locust moves from one locality to another in immense hordes, and birds usually migrate is flocks.

Aggregations may be permanent such as societies of social insects such as termites, ants, bees and wasps; or temporary. The temporary aggregations are formed when certain animals become gregarious by coincidence or for some mutual benefit. A good example is the gragarious habit observed in many species of membracid insects (Homoptera) and sometimes the same host plant lodges two different gregarious species, the individuals of both crowding together and mingling with each other very closely. Such close harmony is indicated by *Oxyrhachis tarandus* and *Otinotus oneratus*, both of which live on the plant *Prosopis spicigera*. The egg masses of the two species are very often laid so close to each other that egg slits of one species partially overlap the other. According to **Ananthasubramanian** and **Ananthakrishnan** (1975), the gregarious species happen to be highly prolific and they lay egg masses in close proximity, the nymphs as well as adults showing very little tendency towards migration with the result that several generations are passed through on the same plant, often on the same twig. They have recognized following kinds of aggregations in insects—1. Certain species (*e.g.*, *Leptocentrus moringae*, *Telengana nigrodata*, etc.) remain gregarious as adults and solitary as nymphs; 2. Some species (*e.g.*. *Coccosterphus tuberculatus*) remain solitary as adults, and gregarious as nymphs: 3. Some species such as *Leptocentrus rhizophagus* remain gregarious in I instar, and solitary thereafter ; 4. The species of *Oxyrhachis krusadiensis* and *Gargara mixta* remain gregarious as ,both nymphs and adults but not living with other species; and 5. Certain gregarious species live with other gregarious species as both nymphs and adults (*Oxyrhachis tarandus*, *Oxyrhachis refescens*, *Otinotus oneratus*).

Causes and advantages of aggregations : It is very often the environment that derives animals into collective groups. Scarcity of space, light, utilization of the same food and shelter, collective breeding and various other conditions induce the animals to aggregate or congregate. These aggregations are capable of tolerating different ecological hazards more efficiently than they have been living solitarily. Insects and vertebrates survive the acute cold of winter by forming groups which help to generate, retain and conserve heat. This is one of the basic advantages of aggregations and is termed as the **group survival value**. Coveys of bobwhite quail roost in close circles, at night. Perhaps this enables detection of predators approaching from any direction but by that behaviour the birds can tolerate lower air temperatures and for a longer time than isolated birds can. Similarly, mice huddle in low air temperatures, a behaviour that reduces heat radiation and consequent need for frequent feeding.

Further, a single muskox or bison may succumb to a pack of wolves. When in a group, the males form a circle facing outward with the females and young inside, whereby they are usually able to ward off the attack. Similarly, a single wolf has difficulty in killing a deer ; a single coyote, in killing a pronghorn antelope. But in packs the wolves can overpower a deer and a pack of coyote can chase a pronghorn to exhaustion.

All these beneficial effects of aggregations, however, lost if the aggregation is either too small or too large. For example, the longevity of *Drosophila* is greatest with a population density of 35 to 55 flies in 28-g culture bottle. Smaller densities are unable to control the growth of the yeasts on which they feed ; greater densities exhaust the food supply and excessive amounts of excreta accumulate.

3. SOCIAL ORGANIZATION

There are many sorts of social organizations that operate in animal populations. They range from those of bees, ants, wasps and termites, which rival only urban man in their degree of division of labour and responsibility among individuals in the population, to those of certain fish and birds, which show well-developed social organization during certain periods, such as the mating seasons, but which may show much weaker organization at other times. In highly organized insect societies, **specialization** occurs both in morphology and behaviour. The primary castes of termites and ants are the winged reproductive males and females, the wingless sterile soldiers that possess large mandibles and irritating glandular secretions, and the smaller, wingless often sterile workers. The soldiers defend the colony against predacious enemies ; this function is assumed by workers in bees and wasps, among which a distinct soldier caste is lacking. In termites, the soldiers may be either males or females ; in ants they are females. The worker caste in ants is usually female, but in higher termites it may consist of either males or females. In primitive termites the nymphs of other castes substitute for workers. The workers collect food, cultivate gardens of fungi, take care of domesticated aphids or coccids, feed the other castes, and built shelters.

It has been argued cogently by **Wynne-Edwards** (1962, 1964) that social organization may be an extremely important mechanism in the regulation of population density for certain animals, especially vertebrates. The precise role of social organization in population regulation is not clear, and the mechanisms by which it has evolved are extremely controversial. But the existence of social organization within animal populations can be demonstrated and a population's social structure may affect its density regardless of whatever other effects it may have on the population. The most important types of social organization that can act to control the sizes and distribution of animal populations are territoriality and social hierarchies.

(a) Territoriality : Many animals 'stake out' a specific volume of space for their activities. These activities may include nesting, feeding, and a number of other functions. The territory they have staked out is defended with great intensity against invasion by other individual of the same species. In some cases, this defense will be extremely aggressive, often involving actual bloodshed. In even more instances, the confrontation will be highly ritualized, with the threat of attack being much more important than the attack itself. The type of defense depends largely on the evolutionary level of the behaviour mechanism ; ritual confrontation seems to be much more advanced than genuine fighting. Entry into the territory by an individual of another species will provoke a very different reaction. If the territorial animal perceives no threat from the visitor, there will be essentially no response whatever, but if he does perceive a threat, the response will be extremely aggressive.

Further, the territorial instinct provides a division of the available space into more or less discrete subvolumes. There may be some overlap, or there may be none. Each territory represents the amount of space for nesting or feeding by a single individual or nesting pair. The number of territories is thus related to the total amount of energy, nutrients, etc., which are available to the species. If these change in time, the number of territories may also change. Size of any specific territory is a function of both the total number of nesting pairs that can be maintained in the area in question and the relative ability of individuals to defend them. Consequently a very strong individual will be able to maintain a larger territory than a weak one. Thus, in species with a well-developed territorial instinct, all individuals that can maintain a territorial claim have an excellent probability of extracting from it sufficient food for themselves and their offspring. Those that cannot effectively excluded from reproduction and/or feeding. This is an effective mechanism for maintaining population size at a reasonable maximum, both by controlling the amount of reproduction in the population as a whole and by limiting the number of individuals who can feed to a number that the ecosystem can sustain. In addition, it insures that the strongest individuals will tend to reproduce, because they obtain territories first and maintain them most effectively, and that those members of the populations who starve or do not reproduce will be the weakest ones. It further guarantees that the strongest members will always have sufficient food and space, by selective mortality of weak individuals to adjust demand to supply rather than by sharing the burden over the whole population.

Territorial concepts were first developed in relation to birds, among which male establishes a territory from which he derives off all other males of his species, and sometimes females other than his male also, but generally ignores those of different species. But later on many mammals, ranging from bears to deer mice, were found to exhibit territorial behaviour, as do lizards, fishes and some insects.

In the views of **Clapham, Jr.** (1973), territoriality is a factor in the forces of natural selection acting upon the population as well as a mechanism for regulating the population. For example, in sea birds and other animals whose nesting space is very small compared to their feeding area. The feeding areas for these birds cover vast areas of the sea with no subdivision whatever into individual territories, but their nesting space consists of very tiny sites in closely crowded areas. The number of nesting sites, however, is closely regulated by tradition and nesting does not take place outside the traditional areas. Thus, there is intense competition for traditional nesting sites, but no nesting elsewhere. The net result of these taboos appears to be equivalent to that of territoriality. Those individals have attained a nesting site have a high probability of reproducing successfully. Those that have no nesting site are prevented from reproducing just as in territoriality, this mechanism seems to provide a ceiling on reproduction and to assure that the strongest individuals (*i.e.*, those that obtain one of the traditional nesting sites) are the ones that carry on the population.

(b) Social Hierarchy : Implicit in the idea of territoriality is that some individuals are "better" in some fashion than other individuals in the population. This may be shown in greater capabilities of certain individuals to keep and maintain territories, or it may also be shown in a discrete social hierarchy within a non-territorial species. The most typical social hierarchy in nature is termed the **pecking order**. The pecking order is the name which is derived from the social order by which domestic barnyard fowl—that have rather well-developed pecking orders—peck at each other without fear of retaliation. Each individual in the population is known to all other individuals in the population, and each has a social rank. The order in which individuals feed or obtain nesting sites depends on this rank, with individuals of low rank deferring to those of higher rank. When food and nesting sites remain in adequate supply for the entire population, all individuals have access to them. When they are not, only the animals at the top of the hierarchy remain successful in obtaining them. The rest starve, are excluded from nesting sites, or are inhibited in their sexual development. The pecking order, thus, can be an exceedingly effective means of pegging the population size to the current state of the environment, generally the availability of food, water, or nesting space, while insuring that a number of individuals in the population both survive and reproduce.

4. PSYCHOLOGICAL FACTORS

There are certain reactions by populations to unusual conditions, most commonly crowding, which do not come into play under normal conditions, and which seem like breakdowns in the normal psychological balances of the organisms. These include **cannibalism, inability to breed** or **care for young, increase in rate of spontaneous abortion** and similar problems. In many species, they act to control the population size when the more normal controls have failed.

An example of a relatively simple psychological factor acting to control population size is shown in the fish guppy, *Lebistes reticulatus* (**Silliman** and **Gutsell**, 1958). When stable experimental populations are maintained by regularly removing a percentage of the fish, significant numbers of the young survive, although some may be cannibalized by their parents. When no artificial predation is practiced the guppies breed continuously, but they remove the entire breeding surplus through cannibalism. Evidently, the normal control mechanism for guppy populations is predation from other fish higher in the food chain. But if, for any reason this mechanism is lost, the population can regulate its own numbers through cannibalism.

Such psychological regulation of population has also been studied in albino rat (**Calhoun**, 1962). When rats were raised in densities higher than normal, they showed psychological abnormalties such as hypersexuality, homosexuality, asexuality, cannibalism, inability of a mother to raise her pups successfully to weaning, increased rate of spontaneous abortion, breakdown in the premating rituals and abnormal crowding around certain places such as food hopper and water fountains. Different biotic factors of the environment thus tend to modify the activities of animals like the abiotic factors.

CHAPTER 5

ANIMAL POPULATION

The word population (L. *populus*, people) which originally referred to a group of people occupying a particular space, now includes groups of organisms occupying a particular space. Different ecologists have defined the population variously. **Odum** (1971) has defined population as a collective group of organisms of the same species (or other groups within which individuals may exchange genetic information) occupying a particular space. **Clapham, Jr.,** (1973) defined population as the total assemblage of individuals of a given species found in any ecosystem under study. **Krebs** (1972) **Smith** (1974), and **Ananthakrishnan** and **Viswanathan** (1976), are basically agreed upon the definition of the population which considers it as a group of organisms of the same species occupying a particular space at a particular time. Anyhow, population is one unit through which energy flows and nutrients are cycled ; it is a self-regulating system that helps in maintaining stability in the ecosystem and its properties include such parameters as abundance and population density, range, genetic variability, adaptations of the species to its environment, demands of the species on the environment, and factors associated with population growth, such as birth rate (natality), death rate (mortality) and age distribution. The study of the numbers for organisms and what determines their abundance and distribution is called **population ecology**.

Further, the ultimate constituents of the population are **individual organisms** that are potentially interfertile. The population may be subdivided into **demes** or **local populations**, which are groups of interbreeding organisms, the smallest collective unit of a plant or animal population. A population has characteristics or "biological attributes" which it shares with its component organisms, and it has characteristics or "group attributes" unique to the group. Among the former, the population has a life-history in that it grows, differentiates, and maintains itself as does the organisms. It has a definite organization and structure that can be described. While, group attributes such as birth rate, death rate, age ratio and genetic fitness, apply only to the population (see **Odum**, 1971).

POPULATION DENSITY

The density of a population refers to its size in relation to some unit of space or observed time. The size of the population can be measured in several ways, including **abundance** (absolute number in population), **numerical density** (number of individuals per unit area or volume), and **biomass density** (biomass per unit area or volume). The density of a species population can be expressed either with reference to total area **(crude density)** or with reference to the actual area of habitat available to the species **(ecological density)**. Thus, we might have a crude density of 500 rabbits per square mile but if only half of the square mile had suitable habitat for rabbits, the ecological density would be 1000 per square mile of rabbit habitat. When the size of individuals in the population is relatively uniform, as mammals, birds or insects, then density is expressed in terms of number of individuals (numerical density). But, when the size of individuals is variable, such as true of fishes, trees or mixed populations, measurement of biomass will be satisfactory as a measure of density (biomass density). To measure density of a population in terms of biomass, one can take wet weight, dry weight, volume and carbon and nitrogen weight.

The density of organisms on any area varies. It may change with the seasons, with weather conditions, with food supply, and with many other influences. There is, however, an upper limit to the density of a population within a unit area, imposed by size and trophic level. Generally the smaller the organism, the greater its abundance per unit area. A 100 acre forest will support a greater number of woodland mice than deer. A forest stand will contain many more trees 2 to 3 in. dbh(diameter breast height) than trees 12 to 14 in. dbh. The larger its size or the higher its position on the trophic levels, the less is the numerical density of an organism. Further, the existence of a population in a particular area for a given time depends upon its rate of reproduction (natality) and mortality or death rate, besides the rates of immigration or ingress and emigration or egress. These phenomena exhibit structural attributes of a population and are intimately correlated with the functional aspects such as miantenance, growth and expansion of population.

NATALITY OF POPULATION

Populations increase because of natality. Natality is equivalent to birth rate and is an expression of the production of **new individual** (*viz.*, reproduction) in the population by birth, hatching, germination, or fission. At this stage, two aspects of reproduction namely fertility and fecundity must be distinguished. The fundamental notion of **fertility** is an actual level of performance in the population based on the numbers born. While **fecundity** is the potential level of performance (or physical capacity) of the population (**Krebs, 1972**). For example, the **fertility rate** for an actual human population may be only one birth per 8 years per female in the child-bearing ages, wheras the **fecundity rate** for humans is one birth per 9 to 11 months per female in the child bearing ages.

Natality rate may be expressed as the number of organisms born per female per unit time. The crude natality rate of a population can be expressed as follows :

$$\text{Birth (Natality) rate (b)} = \frac{\text{number of births per unit time}}{\text{average population}}$$

or

$$b = \frac{dNn}{Ndt}$$

where b = natality rate per unit time, d = entity that is changing, N = initial number of individuals in the population Nn = number of new individuals added to the population by natality, t = time.

The birth rate is the function of the density of the population. As a general rule, if the population density is unusually low, the birth rate is also low, because the probability of males and females finding each other to mate is small. If population density is unusually high, the birth rate may also be relatively low, because of inadequate nutrition or the physiological or psychological aberrations associated with crowding. There is often an optimum density at which the birth rate is maximized. This is generally a relatively low density. Thus the **maximum** or **absolute natality** is the theoretical maximum production of new individuals under ideal conditions. To attain this maximum a species would exist under ideally optional ecological and genetic conditions. **Ecological** or **realised natality** refers to increase of population under given set of environmental conditions. It is not constant for a population but may vary with the size, composition and fecundity of a population.

FECUNDITY

Species vary greatly in the characteristic number of generations, broods or litters produced per year, and in the sizes of them. Protozoans often divide so rapidly that they produce a new generation every few hours. Plankton organisms, less fecund, may produce a new generation every few days. Many vertebrates breed but once a year, some large animals only once every two or three years. Several species of small birds and mammals have two or more broods per year. Rodents may continue to breed throughout the winter under favourable environmental conditions, so that their reproductive potential is enormous.

The maximum size of a litter is determined by the physiological and morphological characteristics of the species. In mammals, which produce viviparous young, the size of uterus and body cavity as well as the number of mammary glands for suckling the young after birth act as limiting factors for the size of the litter. In birds there is a limit on the number of eggs that one individual can cover and successfully incubate. However in species that do not take care of their eggs after laying, the number produced may be limited only by the energy resources of the parent.

The number of eggs or young produced per litter is correlated inversely with the amount of attention (*viz.*, parental care) that they require. When parental care is altogether lacking, invertebrates may lay 1,000 to 500,000,000 eggs at one maturation ; where there is some protection afforded by brood pouches, 100 to 1,000 eggs may be laid ; with a high degree of brood protection, 1 to 10 or more eggs may be laid. Mammals seldom have more than a dozen young in a single litter and, in larger species, usually only one. Characteristic clutch size among birds varies from 1 to 15 ; rarely, 20.

Further, there is a limit on the size of the brood or litter that adult warm-blooded animals can successfully feed and raise to maturity. There is no advantage, for example, for starlings to have broods larger than five. In larger broods, each individual receives less food, and hence has less vigour and weight on leaving the nest. In such weak individuals, mortality increases either before fledging or in subsequent months (**Perrins**, 1965). In those species that feed their young in the nest, the clutch size has evolved through natural selection to the greatest number that can be hatched and raised successfully through efforts of the adults (**Lack**, 1967). In those species whose young leave the nest and feed themselves at hatching, the clutch size depends in large part on the capability of the female to mobilize energy in her body to produce eggs of a particular size (**Ryder**, 1970). The variability in clutch, and litter size for most species allows them to take advantage of temporarily improved conditions.

The size of brood, litter or clutch is also regulated by weather. For example, the clutches laid by birds during periods of hot weather are usually smaller than those laid when temperature is moderate (**Kendeigh**, 1941). Clutches laid by related species in temperate latitudes tend to be larger than those laid in the tropics. Likewise, the fecundity of white-tailed deer is higher with good forage than with poor forage. The reproduction is generally more successful after periods of high mortality than during years of abundance.

MORTALITY OF POPULATION

Mortality is the population-decline factor and thus, in terms of its effect on the group, is antithetic to natality. As natality can be expressed as a rate of gain or birth of individuals in unit time mortality can be expressed as a loss of individuals in unit time—the **death rate**. Generally mortality is expressed as **specific mortality**, that is, the number of members of an original population dying after the lapse of a given time. The crude rate of death of a population can be calculated by this equation :

$$\text{Death rate (d)} = \frac{\text{number of deaths per unit time}}{\text{average population}}$$

The rate of mortality (death) is related with density like natality. Mortality is almost highest at very high densities because the hazards of over crowding and the greater likelihood of concentrated predation or spread of disease, but it is often quite high at very low densities as well, because a number of individuals of a given species are often better able to survive during a period of stress than is a single individual. For instance, heat generated by a cluster of bees is sufficient to allow survival of the cluster in temperatures low enough to kill the bees were they not clumped together.

The death rates vary among species and are correlated with rates of reproduction (natality). The death rate of a species is influenced by a number of factors such as destruction of nests, eggs or young by storms, wind, floods, predators, accidents, and desertation of parents, but of fundamental importance is the number of young that are born in relation to the carrying capacity of the habitat. When more young are born than the habitat can support, the surplus must either die or leave the area. Because, the number of survivours is more important than the number dying, so mortality is better expressed as survival or as **life expectancy**, the average number of years that members of a population have left to live.

Mortality rate is usually expressed as a percentage of individuals dying within a given time. The mortality rate in many species varies from one age level to another; thus, a mean death rate has only general significance. In birds, however, the death rate is nearly constant once they become adult, and it is then apparent that it varies inversely with adult longevity. In adult penguins, pelicans, shore birds, gulls, and swifts, the annual mortality rate is commonly between 12 and 30 per cent; in herons, hawks, and owls it is about 30 per cent; in ducks, doves, and song birds it is between 40 and 68 per cent, while in gallinaceous birds it is the highest, 60 to 80 per cent. As mortality varies positively with age in the majority of organisms, the specific mortalities at particular ages can be illustrated in the form of life table.

LIFE TABLES

Species differ widely in the number of young produced, each year, in the average age to which they live and in their average rate of mortality. When sufficient facts about a species are known, a **life table** that tabulates the vital statistics of mortality and life expectancy for each age group in the population may be formulated. In such tables, age is usually represented by the subscript index *x* and is some convenient fraction of a species mean life span, such as year or stage of development. The life table is set up on the basis of an initial cohort of 100, 1000, or 100,000 individuals ; and the number living to the beginning of each successive age interval is symbolized as *lx*. Plotting these data gives a **survivourship curve** for the species, and a number of survivourship curves have been worked out for different species. The number dying within each age interval is designated as *dx* and gives a mortality rate. The rate of mortality during each age interval is commonly expressed as the percentage of the number at the beginning of the interval 100 (*dx*/*lx*) and is indicated as *qx*. Survival rate is the difference between the mortality rate and 100 per cent (100—*qx*) and is expressed as *sx*. Life expectancy (*ex*) is the mean time that elapses between any specified age and the time of death of all animals in the age group. For example we can consider following life table for budworms of Canada :

Table : Life table for the 1952–53 generations of the spruce budworm in New Brunswick, Canada (after **Morris** and **Miller**, 1954, source **Kendeigh**, 1974).

x	lx	Factors responsible for dx	dx	qx
Eggs	1000	Parasites	17	2(–)
		Predators	86	9(–)
		Others	6	1(–)
		Total =	109	12
Instar I	891	Dispersal, etc.	428	48
Hibernacula	463	Winter	79	17
Instar II	384	Dispersal	242	63
Instars III–VI	142	Parasites	51	36
		Disease	3	2
		Birds	20	14
		Others	61	43
		Total =	135	95

x	lx	Factors responsible for dx	dx	qx
Pupae	7	Parasites	0·6	8
		Predators	0·7	10
		Others	1·3	18
		Total =	2 6	36
Moths	4 3	Total for generation	= 995·7	99·5

Uses of life tables : Life tables are useful for computing the average longevity of a population, for showing the age composition of a population, for indicating critical stages in the life cycle at which mortality is high, for showing differences between species, for showing the suceess of the same species in different biotopes, for furnishing information of value in game and fish exploitation (yield) and in control of pests.

Types of survival curve : Because which is really vital for the population is not which members die, but which members survive, specific mortality is expressed by **survivorship curve**. If it could be assumed that all members of an original population had the same capacity for survival (environmental effects for the moment are ignored), plotting the number of surviving individuals against time would produce a survivorship curve in the form of a right angle. The curves of survival plotted from life table may be of three types. In type 1 a cohort finds environmental conditions ideal ; all members, born at the same time, live out the full physiological life span characteristic of the species, and all die at about the same time. The survivorship curve of modern industrialized man approaches type 1. In type 2, the rate of mortality is constant at all age groups, so that an individual's chance of living another year is just as good at one age as another. This approximately true for some adult birds. Type 3 shows extremely heavy mortality early in life, as will such forms as the oyster, where most of the millions of eggs spawned never hatch, but those few individuals that survive have a high life expectation there after. Most survivorship curves observed under natural conditions are intermediate between these three types (*e.g.*, deer, annelid worms, insects, and isopods).

AGE DISTRIBUTION OF POPULATION

It is obvious that populations that differ in the relative numbers of young and old will have different characteristics, different birth and death rates, and different prospects. In other words, age distribution is an important population characteristic which influences both natality and mortality. Mortality usually varies with age, as chances of death are more towards the earlier and later periods of life span. Likewise, reproduction (natality) is restricted to certain age groups, for example the middle age groups in the higher animals. The distribution of ages in a population may remain fairly constant, or it may change throughout the generation time. The population age distribution is related to the growth rate of the population, and it can be used to estimate whether a population is expanding or contracting. Further, the ratio of the various age groups in a population determines the current reproductive status of the population and indicates what may be expected in the future. Usually a rapidly expanding population will contain a large proportion of young individuals, a stationary population more even distribution of age classes and a declining population a large proportion of old individuals.

METHODS OF MEASURING THE AGE OF POPULATION

There are several different ways of measuring age, and there are two main ways of presenting age distribution in a population. The simplest measurement for age is the **raw age** itself. In only one species of organism is under investigation, it is probably the best scale to use, in addition to being the simplest. However, it is difficult to compare age distributions of different species using raw ages if the life spans are different, as, for instance, between elephants and mice. For the purpose of comparing age distributions, a useful means of portraying age is as a percentage of total life span. The maximum observed life span of a species is determined, and ages are presented as percentages of that maximum. This presentation format for age data can be applied equally well to any species of organism, regardless of its life span. A related means of presentation is percentage of deviation from mean life span. In this format, the average age at death is computed and ages presented in terms of deviation from this mean age. Both of these formats require that the maximum or mean life span, respectively, be shown for each species, because this information is not presented in data converted to percentage form.

A some what different type of age portrayal is the **ecological or functional age**, where the life span of a species can be divided up into various functional units, such as **prereproductive, reproductive, and postreproductive**, or egg, larva, nymph, and adult. The appearance of individuals of the various functional ages may be quite similar, as in man, or quite different, as in animals that undergo metamorphosis. Functional age breakdowns can be extremely useful in comparing certain features of different populations, such as the relative importance of specific environmental factors on the population as a whole. If we know both the percentage of time spent by an organism in specific functional ages and the environmental factors that have the greatest effect on each age, we have gained considerable insight into the characteristics of the species in question. This knowledge is essential if we are trying to design a procedure to control a best species on an economically important crop, and it is necessary to ascertain which stage in the life cycle of the pest is most vulnerable to attack by which means.

Age pyramids : The first means of portraying age distribution is the **age pyramid.** An age pyramid is a vertical bar graph in which the number or proportion of individuals in various age ranges at any given time is shown from youngest at the bottom of the graph to oldest at the top. It is very useful in monitoring the commericial exploitation of food species by man among other things. Ages may be shown in any of the formats we outlined. An age pyramid represents the age distribution of a living population at a specific moment; thus, as the population age distribution changes over a period of time, the form of the age pyramid does too. From an age pyramid, one can collect the information that whether a population is expanding, contracting, or stable. When compared to the age pyramid of a stable population, if age pyramid shows an increased number of juveniles (*i.e.*, a broader base), it is expanding ; if it shows a decreased number of juveniles (*i.e.*, a narrower base), it is contracting. Consequently, a triangular pyramid will represent a growing population and an urn-shaped pyramid will indicate an increased number of middle aged and old organisms compared to the young. However a bell-shaped pyramid will denote a stationary or stable population having an equal number of young and middle-ages classes.

Biotic potential and environmental resistance : The term **biotic potential** or reproductive potential, refers to the inherent power of a population to increase in numbers when the age ratio is stable and all environmental conditions are optimal. The biotic potential is defined mathematically as the slope of the population growth curve during the logarithmic phase of growth. When environmental condition are less than optimal, the rate of population growth is less. The difference between the potential ability of a population to increase and the actual change in size of the population is a measure of environmental resistance.

The sum of the physical and biologic factors which prevent a species-from reproducing at its maximum rate is termed the **environmental resistance**. Environmental resistance is often low when a species is first introduced into a new territory so that the species increases in number at a fantastic rate as when the rabbit was introduced into Australia and English sparrow and Japanese beetle were brought into the United States. But as a species increases in number the environmental resistance to it also increases, in the form of organisms that prey upon it or parasitize it, and the competition between the members of the species for food and living space, and consequently, population decreases. An equilibrium will be reached either by decreasing the birth rate (natality) or by increasing the mortality rate.

GROWTH FORM OF POPULATION

The growth is the most fundamental dynamic feature that a species population display. Populations characteristically increase in size in a sigmoid, S-shaped or logistic fashion. When a few organisms are introduced into an unoccupied area, the growth of the population is at first slow (**positive acceleration phase**) then becomes very rapid (**logarithrmic phase**) and finally slows down as the environmental resistance increases (**the negative acceleration phase**) until an equilibrium level is reached around which the population size fluctuates more or less irregularly according to the constancy or variability of given environment. The level beyond which no major increase can occur represents the saturation level or **carrying capacity**. The carrying capacity or equilibrium density is represented by the letter K. It is often useful to define the maximum rate of growth of the population. This parameter, generally termed the **intrinsic rate of natural increase**, is symbolized r_0 and represents the growth rate of a population that is infinitely small. Accordingly such type of population growth can be described by following **logistic equation :**

$$dN/dt = r_0\, N\, (K - N)/K$$

If one desires to represent sigmoid growth of the population graphically, he has to plot the time on the X-axis and the number of organisms on the Y-axis, and consequently, will get a characteristic S-shaped sigmoid curve. Human population and growth of yeast, *Drosophila* or rabbit in laboratory conditions, follow such S-shaped population growth.

Another kind of population growth curve, called **J-shaped growth curve** is obtained when the density of the organisms increases rapidly, in compound interest fashion, and then stops abruptly as environmental resistance or other limits become effective more or less suddenly.

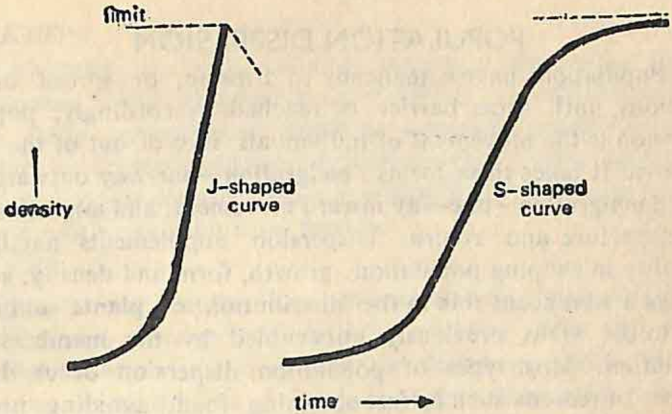


Fig. 5·1. J-shaped and S-shaped population growth curves.

GROWTH RATE OF POPULATION

The rate of growth of a population is expressed as the number of individuals by which the population increases divided by the amount of time that elapses while this population increase is taking place :

$$\text{Growth rate } (r) = \frac{\text{number of births } (b)\text{—number of deaths } (d)}{\text{average population in time interval.}}$$

The actual change in population number ($\triangle N$) over any span of time ($\triangle t$) is equal to rN. This can be written $\triangle N/\triangle t = rN$ or, using the symbology of the calculus, the rate of change of the population at any instant time (dN/dt) can be expressed $dN/dt = rN$. This is equivalent to saying that the number of individuals at any arbitrary time t, or Nt, is related to the number of individuals at the beginning, N_0, by the equation $Nt = N_0 e^{rt}$, where $e =$ 2·71828........., the base of the natural logarithms.

If r is constant, the growth of population will be exponential. If r is positive ($b>d$), the population shows an exponential increase to indefinite density and if r is negative ($b<d$), it shows an exponential decay to extinction. It is impossible for a population to change at an exponential rate indefinitely. However, there are many cases in which conditions are such that b is substantially larger than d for a period of time, following which conditions change so that d becomes much larger than b. The responses of populations to variations of this sort is an exponential **"population explosion"** during favourable conditions, followed by a **"crash"** when conditions change. Diatom populations in Lake Michigan, USA, for example, undergo such exponential increases at different times of years, triggered by variations in abiotic factors within the lake, followed by equally rapid declines.

POPULATION DISPERSION

Populations have a tendency to disperse, or spread out in all directions, until some barrier is reached. Accordingly, population dispersion is the movement of individuals into or out of the population area. It takes three forms : **emigration**—one-way outward movement; **immigration**—one-way inward movement; and **migration**—periodic departure and return. Dispersion supplements natality and mortality in shaping population, growth, form and density, and also it plays a significant role in the distribution of plants and animals even to the areas previously unoccupied by the members of the population. Most types of population dispersion occur due to a number of reasons such as for obtaining food, avoiding predators, preventing overcrowding, result of action of wind and water, environmental factors as light and temperature, breeding behaviour, physiological reasons as secretion of some hormone or for interchange of genetic material between populations.

EMIGRATION

Emigration under natural conditions occur when there is overcrowding in the migratory locust, lemming, grouse, snowy owl, snowshoe rabbit, Arctic fox, gray squirrel and occasionally in other species. This is generally regarded as an adaptive behaviour that regulates the population on a particular site and prevents over-exploitation of the habitat. Further, it leads to occupation of new areas elsewhere. By dispersing into new localities, there is opportunity gained for interbreeding with other populations leading to more genetic heterozygosity and adaptability.

It is, of course, population pressure that is responsible in large part for the dispersal of the young and extension of ranges into new areas. Under normal conditions adult animals, especially among the higher vertebrates, are well established on their territories and the youngs are forced to seek homes elsewhere. Among insects, there is a relation between emigration and inherited behaviour tendencies. Individual tent caterpillars, both larvae and adults, differ innately in the extent to which they show activity even within same colony. In the development of populations of excessive size, spread of infestations of the insect into new regions is largely by the more active individuals. The outbreak finally terminate when the proportion of sluggish individuals comes to predominate in the population (**Wellington**, 1966). Continuous emigrations are rare and when they occur, result in **depopulation**. Equilibrium of populations is maintained in such circumstances by enhancing the reproductive ability as well as by decreased mortality among the populations.

IMMIGRATION

Immigration leads to a rise in population level, causing an **overpopulation** which may lead to an increase beyond the carrying capacity. These immigrations result in increased mortality among the immigrants or decreased reproductive capacity of the individuals. Both emigration and immigration are initiated by weather and other abiotic and biotic environmental factors.

MIGRATION

Migration is a peculiar kind of population dispersion which involves the mass movement of entire population. This can occur only in mobile organisms and best developed in insects like the butterfly *Danaus plexippus* and in the migratory dragonflies *Libellula quadrimaculata* and *Pantala flavescens* ; in fishes like eels, in birds and in certain mammals. Most two-way migratory movements are rhythmic processes of populations and regular periodicity is a common feature. Very often, environmental periodicities control these migratory movements, as for example day and night rhythm, lunar periods, tides and changing seasons. The monarch butterfly-*Danaus plexippus*, travels very long distances and their migrations are found to be pathed every year through their same conventional routes, and their migratory movements is initiated by the oncoming winter and the return trip being influenced by spring.

In most cases, migration of population may occur for food, shelter, or reproduction. Better utilization of uninhabited or hitherto untouched habitats and their resources is the greatest benefit derived from the migratory movements. However, during migration of population mortality of numerous individuals may occur due to different ecological hazards such as temperature fluctuations, scarcity of food, predation, etc. Anyhow, migration has certain benefits for populations—as it enables wider dispersion of populations ; it avoids intraspecific competition for food, shelter or any other means.

At last we can say that population dispersion is brought about by population increase, improvement of habitats or deterioration of habitatats, sparseness of population and by changes in or extremes of weather.

REGULATION OF POPULATION SIZE

The inherent tendency of all animal populations is to increase in numbers. But this increase in number is however, not infinite since the carrying capacity of the environment always imposes a restriction upon it. Thus, after reaching the carrying capacity level, the population density tends to fluctuate above and below this level and such fluctuations in population between upper and lower limits tend to give some stability to the population. The nature of the processes that regulate the numbers of plants and animals is a major problem of population ecology.

Many groups of animals and plants are provided with unique and intrinsic self-regulatory mechanism such as failure of reproduction and self-inflicted mortality for controlling the size of the population. Populations grow when natality exceeds mortality, and they decline when mortality exceeds natality. However, limitation of animal numbers on a population is brought about by the action and interaction of two basic regulatory processes namely **density independent** and **density dependent factors**. Density independent factors are the extrinsic factors which tend to **regulate the density of a** population under different conditions, appearing to act on the population and inflict loss of individuals irrespective of the population density. Variations in space or cover, favourable weather and food occur independently of population densities and may cause drastic changes in the abundance of animals. Such ecological or environmental factors influcence negatively or positively all the individuals of a population irrespective of density.

The density dependent factors are intrinsic or biotic factors and they depend on coaction between individuals within the same population or between populations of different species. Density-dependent factors may stabilize populations at an asymptote, the level of which is determined by the carrying capacity of the environment. Some of the important density dependent factors are competition, reproductivity, predation, emigration and disease. The combination of factors or any specific factor involved in the density dependent action may vary from species to species. Further these species have been known to display the property of intercompensation. According to intercompensation, if there is a change in the environment to relive the population of pressure from an existing effect, then the population increases till it reaches a level when the second effect takes over. Thus, if the predators that normally keep herbivorous animals down are removed, the population of herbivorous may increase to become overcrowded and result is starvation. A supply of abundant food at this junction would make the individuals susceptible to diseases due to the intensity of crowding (**Wilson** and **Bossert**, 1971). Generally, the population fluctuations controlled by extrinsic factors tend to be irregular and correlated with the variation in one or more major physical limiting factors such as temperature, food, water, etc., while fluctuations of populations controlled by intrinsic factors exhibit regularity and population cycles.

POPULATION CYCLES

Populations are said to be cyclic when they alternatively errupt and subside in a more or less uniform manner between high and low levels of density. Different animals exhibit population cycles different times. The best established cycles of population density of fluctuations are those of periodicities of 3-4 years and 9-10 years. The 3-4 year cycles are most commonly observed in many birds such as snowy owl, willow ptarmigan, capercaillie, Blackgame, Hazel grouse etc. ; mammals such as lemmings, voles, arctic foxes, etc., and fishes. 9-10 years cycles of population density fluctuations have been observed in birds such as ruffed-grouse, sharp-tailed grouse, willow ptarmigan, etc., and mammals such as snowshoe rabbit, muskrats, **Canada lynx**, etc. Among invertebrates, insect pests of coniferous ferests in Germany fluctuate in periods variously from 6 through 18 years. *Asterias forkesi* is found to contain periodicity of 14 years.

Attempts to explain these vast oscillations in numbers on the basis of climatic changes have been unsuccessful. At one time it was believed that these were caused by sunspots, and the sunspots and lynx cycles do appear to correspond during the early part of the nineteenth century. However, the cycles are of slightly different lengths and by 1920 were completely out of phase, sunspot maxima corresponding to lynx minima. Attempts to correlate these cycles with other periodic weather changes and with cycles of disease organisms have been unsuccessful.

The snowshoe hares die off cyclically even in the absence of predators and in the absence of known disease organisms. The animals apparently die of "shock" characterized by low blood sugar (hypoglycemia), exhaustion, convulsions and death, symptoms which resemble the "alarm responses" induced in laboratory animals subjectcd to physiologic stress. Visualizing this similarity, **J.J. Christian** (1950) proposed that their death, like the alarm response is the result of some upset in the adrenal-pituitary system. As population density increases; there is increasing physiological stress on individual hares owing to crowding and competition for food. Some individuals are forced into poorer habitats where food is less abundant and predators more abundant. The physiologic stresses stimalate the adrenal medulla to secrete **epinephrine**, which stimulates pituitary via the hypothalamus to secrete more ACTH (adrenocorticotropic hormone). This, in turn, stimulates the adrenal cortex to produce corticosteroids, an excess or imbalance of which produces the alarm response or physiological shock.

In the latter part of the winter of a year of peak abundance, with the stress of cold weather, lack of food and the onset of the new reproductive season putting additional demands on the pituitary to secrete gonadotropins, the adrenal-pituitary system fails, becomes unable to maintain its normal control of carbohydrate metabolism, and low blood sugar (hypoglycemia), convulsion and death ensue.

According to **Kendeigh** (1974) several instrinsic factors such as disease, predation, food factor and natural selection affect animal cycles in addition to several extrinsic factors such as weather, solar radiation, and so on.

CHAPTER 6

BIOTIC COMMUNITIES

A monospecific assemblage of living organisms is a population. An assemblage of population living in a defined area or habitat is called **biotic community**. A biotic community is thus is a complex assemblage of **microbial community, plant community** and **animal community. Allee** *et al.* (1949) has defined community as *a natural assemblage of organisms which, together with its habitat, has reached a survival level such that it is relatively independent of adjacent assemblages of equal rank ; to this extent given radiant energy, it is self-sustaining*. However, **Ananthakrishnan** and **Viswanathan** (1976) considers community as any assemblage of ecologically related organisms composed of two or more species. The community units may be very large, like the continent-wide coniferous forest, or very small like the community of invertebrates and fungi in a decaying log. A different community occurs in each different habitat and environmental unit of larger size, and in fact the composition and character of the community is an excellent indicator of the type of the environment that is present.

The importance of the community concept does not lie so much in the populations themselves, as in the set of functional interactions between them. In preceding chapter, we have observed how individual populations interact strongly with one another, both as food supplies and as a population regulatory agents. But populations also interact with other members of their communities in much more ingenious fashions, which may have little direct role in the regulation of the specific groups involved, but which are fundamental to the maintenance of the community as a whole and hence to the existence of any species in the community. For instance, there is no direct interaction between deer and nitrogen bacteria in a forest. They belong to different food chains ; both have their own population dynamics, and they are regulated by different aspects of the physical or biotic environment. Yet without nitrogen bacteria, nitrogen could not cycle, and deer could not exist (nor any other form of life, for the matter). Conversely, without members of the grazing food chain such as deer, nitrogen bacteria would have no nitrogenous wastes to feed upon. Thus, in a biotic community there exists a great interdependence among species of different communities (*i.e.*, plant community, microbial community and animal community). The very existence of any population is due to the fact that other populations also exist which make available energy and nutrients, regulate population size, recycle wastes, and buffer the community against the vagaries of the physical environment Population exist, in fact, because they are parts of biotic communities.

Further it has been suggested that the community is analogous to a superorganism in which the various component organisms may represent the structural and functional units in the same manner that different types of cells make up an organism. As such, a community exhibits all those life processes of an individual organisms that were mentioned elsewhere ; that is, metabolism, reproduction, growth, and adaptive responses to environmental fluctuations (see **Vernberg and Vernberg**, 1970).

TYPES OF COMMUNITIES

According to **Kendeigh** (1974), the communities may be distinguished as major or minor. **Major communities** are those which, together with their habitats, form more or less complete and self-sustaining units or ecosystems, except for the indespensable input of solar energy. **Minor communities**, often called **societies**, are secondary aggregations within the major community and are not, therefore, completely independent units as far as circulation of energy is concerned.

COMMUNITY STRUCTURE

As communities are dynamic entities of an ecosystem, they include populations that interact constantly with one another, with the patterns of interaction showing continuous variation, both in time and in space. But at all times and in all situations there is a pattern to the organization of the community that is ultimately determined by the complex of environmental factors characterizing the community. This characteristic pattern often termed **community structure**, is reflected in the roles played by various populations, their ranges and the types of areas they inhabit, the diversity of species in the community and the spectrum of interactions between them, and the precise flow patterns of energy and nutrients through the community (**Clapham, Jr.**, 1973). Consequently the structure of community includes following aspects :

ECOLOGICAL NICHE

Each species has a specific position within the community designated as **ecological niche**, and this very often stand for the functional status or total role of the species within the community. The niche comprises all the bonds between the population and the community and ecosystem in which it is found. These bonds include factors such as the tolerance ranges and optima for all abiotic environmental factors, the sorts of organisms that can be utilized for food by the population, as well as the organisms that feed upon it, the areas in which the species can live, and the population structure of the species. Every population has an ecological niche and this niche is the major determinant of the structural, physical and behavioural adaptations of the population. Recently, the concept of niche has been extended to categories such as **spatial niche** or **habitat niche, trophic niche, climatic niche**, etc.

Different communities in ecosystems characterized by similar environments are often exceedingly similar in their structure, and they may contain one or more niches that are essentially identical. **The adaptations of populations inhabiting these niches may also be** exceedingly similar, even though they are totally unrelated. For example, the succulent (xerophytic) plants of the southwestern United States are cacti ; in the deserts of şouthern Africa, there are plants of the spurge family that are virtually identical. In two pairs of birds namely the little auk (a bird of order of gulls) and Magellan diving petrel (a bird of the order of albatross) ; and the eastern meadowlark (an American icterid bird) and yellow throated longclaw (an African Motacillid bird), though each bird is totally unrelated to the other, but they all are virtually identical in appearance and basic adaptations. This phenomenon of similar but unrelated species in different geographical areas is called **ecological equivalence.** It gives much insight into the essence of the niche. The adaptations of an organism to its niche are the result of an extensive period of evolutionary change. In order for two unrelated species to have evolved to a point of ecological equivalence, the niches to which they are adapted must be essentially identical, even though they may be separated by many thousands of miles. It would be impossible for different species to inhabit the same niche in widely separated areas if the niche and the interactions of which it is composed were a property of population alone. Clearly, the structure of communities set in similar environments is so similar that essentially identical niches can develop in them. This means that the principles by which biologial communities are organized surpass the individual communities, and that the evolution of species may proceed in a fairly predictable manner, controlled by the structure of the community in which it exists, which itself is a function of the fundamental abiotic features of the environment.

On the other side, no two species populations can occupy the same niche in a single community (cf. **Gause's principle**). In such a case, one will always be superior and derive the other into local extinction through competition. For different species to survive within a single community, there must be some difference between their niches. In Gause's classic experiment, for example, different species of *Paramecium* were raised together. When *P. aurelia* and *P. caudatum* were the experimental species, only *P. aurelia* was left after sixteen days. The niches of these two species are essentially identical, and the more rapid population growth of *P. aurelia* allowed it to overwhelm *P. caudatum*. However when *P. bursaria* and *P. caudatum* were cultured together, both survived. Even though their food requirements are the same, they live in different parts of the culture chamber, and this simple separation is sufficient to enable each species to have a separate niche-and hence to survive.

There remains a possibility of an overlapping of niches of different species. Of the six species of parasitic Hymenoptera attacking the cocoons of the sawfly *Neodiprion swainei* the four indigenous species overlapped in their distribution although each species occupied one position in the **niche space** ; some even developed a 'zone of dominance' over the other species (**Price, 1971**). If the amount of overlap is very small then the two populations can exist simultaneously in essentially separate niches. If the overlapping is virtually complete, then the population that is more successful in exploiting the environment will drive the less successful population into extinction through interspecific competition. For example, locusts usually eat grass and wild plants and do not then compete with man, but when large swarms migrate, they eat crops and so compete with man for food. However, abundance of food supply in situations where the same food resource was exploited by different species. averted competitive exclusion. Many closely allied herbivorous fishes coexist in the same habitat utilizing the same food and this is attributed to the sumptuous supply of algae (**Freyer, 1959**), generally among two populations.

The number of potential niches in the community is a function of the degree to which the development of community under a given environmental regime leads to a divergence or separation of partially overlapping niches. If the tendency for separation is high, then the community will be more complex than if it is low. Stable environments which are characterized by communities having a large number of separate niches, foster the separation of niches, whereas harsh environments characterized by communities with fewer niches, tend not to foster niche separation. The mechanism for niche separation is natural selection.

SPECIES ABUNDANCE AND DIVERSITY OF THE COMMUNITY

The number of populations in a community varies greatly over a wide range. Some communities of one prominent plant species (single population) may occupy a single layer of a habitat such as the desert salt-grass community or any other community of tundra, while, the communities, such as tropical rainforest or a coral reef, may be multispecies and multilayered system and may contain thousands of populations. The number of species in the community is termed the **richness. Species diversity** closely follows the number of constituent populations, when populations constituting the communities are small there tends to be more diversity, because the coexistence of different species in a community is regulated by the basic resources available within the ecosystem. But species abundance is not the only basis for measuring species diversity in all cases. A gradual increase in species diversity is apparent from the polar regions to the tropics.

Since a community is a natural assemblage of organisms that have evolved together to a high collective persistence level, its structure is based on its relatively distinctive species composition—which may be either sharply different from that of an adjacent community or may show degrees of overlap. Some species are found in only one community (**an exclusive species**), whereas others live in many communities (an **ubiquitous species**). Typically in the aggregation of species that make up a community, only a few species are abundant in number of individuals or biomass (weight) and the majority of species are relatively rare.

COMMUNITY DOMINANCE

Not all organisms in the community are equally important in determining the nature of the whole community. Out of the numerous kinds of organisms (or species) that might be present in a community, a few species generally exert the major controlling influence by virtue of their numbers, size or activities. This phenomenon where in various species within the community are dominated by one species or more than one species, is termed **community dominance**, and the dominating species are recognized as **community dominants.** Plants are more frequently dominant in terrestrial communities than are animals. In aquatic communities, animals are relatively more important in this role, although dominance is often not developed.

According to **Clements** and **Shelford** (1939), dominance is most commonly expressed in the reactions of an organism on its habitat. Community dominants shoulder the full impact of the climate or the environment but modify this effect for other organisms within the community by tempering light, moisture, space, and other conditions. Only those other organisms that find these modified physical conditions tolerable can exist within the community. Furthermore, dominants are ordinarily the most prominent species in the community, make up its greatest mass of living material (**biomass**), and serve as the major source of food, substrate, and shelter for the animals that are present. In a forest community, trees are dominant. They decrease light intensity, increase the relative humidity, intercept precipitation, monopolize most of the moisture and nutrients in the soil, decrease wind velocity, and furnish shelter and food for animals. Grasses play a similar, though less conspicuous, role in prairie communities ; sedges, rushes and cattails in marsh communities ; sagebrush in the arid habitat of the Great Basin ; mussels and barnacles on a rocky seashore ; and so forth.

In certain cases, community dominance is demonstrated in **coactions**, direct effects of organisms on each other. In some fresh water ponds, carp and suckers may consume much of the submerged vegetation. This coaction thus prevent constituents from assuming their usual role in community, and by so much prevents the occurrence of animal species that depend directly upon the plants. These fishes also react upon the habitat by stirring up the bottom, from which they derive organic matter, thereby greatly increasing the turbidity of the water. Penetration of light into the water is reduced, greatly handicapping sunfish, bass, and other species which locate visually.

In ancient days, bison on great plains of U.S.A. fed on the luxuriant taller grasses more extensively than on the short grasses, with the consequence that, over extensive areas, short grass species replaced tall grasses almost entirely. Thus bisons were coactant with and dominant over the composition and character of the community (**Larson**, 1940). Similarly, overpopulations of the European rabbit alter the character of the forest by feeding upon the seedlings of oak, beech, and hornbeam to the exclusion of other species. When introduced into Australia, the European rabbit converted grassy areas into desert-like tracts. Though, animals are more common coactors than plants, plant pathogens may occasionally exert dominance in this way. For example, the pathogenic fungus-chestnut blight virtually eliminated the chestnut population from the deciduous forest of eastern North America during the first few decades of the twentieth century.

Further, in a forest community in which trees are dominant, species in the lower stratum of shrubs modify the habitat still further and even the herbs exert some control over the physical conditions on the surface of the ground. The herbs and shrubs are termed as **subdominant species** and they have to tolerate the conditions established for them by dominants, but they in turn are the modifier of the community composition in a secondary manner.

TROPHIC STRUCTURE OF THE COMMUNITY

The diversity and hierarchical arrangements of population (*i.e.*, dominant-subdominant communities) or niches in a community present only one aspect of structure of community. Equally important are those patterns of interpopulation interactions that bind all populations together. The most important of these is the **trophic structure**, which determines the patterns of movement of energy and nutrients through the community. Through the **food web** one can made the graphic depiction of the actual flow of food materials from population to population through the community. Communities, at least major ones, have many trophic levels such as producers (most green plants) consumers (most animals) and decomposers (most microbes). The organisms most consistent in their trophic levels are the green plants ; few of them consume other organisms. (Some autotrophs, however, do gain significant quantities of their nutrients from other plants, or even animals. These include certain epiphytic plants like the mistletoe, whose habitat is the upper branches of larger trees, as well as the insectivorous plants such as venus's flytrap and pitcher plant. with regard to energy, all of these plants are autotrophs ; with regard to nutrients, they are partially "herbivores" or even" carnivores".) The situation is less well marked in herbivores. Some eat only plants (except when they ingest an animal by mistake). But some like the ostracod, may regularly eat animals if they catch them, even though their usual diet consists of plants. Carnivores are still less consistent. Many species are predominantly primary carnivores ; that is, they eat mainly herbivores. Many others are mainly secondary carnivores, with a diet composed largely of primary carnivores and so forth. But few carnivores being highly selective in their diet, will avoid eating any animal they are able to catch, if they are hungry. In addition, many animals, such as raccoons, bears and man are omnivorous and will feed at all trophic levels present in the community, while others, such as frogs and many insects, occupy different trophic levels at different stages in their life cycles.

The food web of a community often has great amount of flexibility in the pathways through which energy may flow. In the community, though all animals have some choice regarding their food supply, some of them, however, have the opportunity to feed at more than one trophic level. This choice provides a multitude of potential pathways for energy flow, and it has an important role in the stability of the community.

COMMUNITY STABILITY

One of the most important considerations about communities is their stability, or lack of variation in time. There are two discrete senses in which this term is used. The first, **community stability,** refers to the degree of fluctuation in population size of the populations comprising the community. The second, **environmental stability**. refers to the fluctuations in the abiotic factors of the ecosystem. The two types of stability are closely related, and stable communities are generally to be found in stable environments, while unstable environments are more often characterized by unstable communities.

The global range of variation in community stability is extraordinarily broad. Some communities like the tropical rainforest or the coral reef, appear exceedingly stable, and the densities of their populations are constant over long periods of time. Others, such as the tundra, are extremely variable, and they are made up of populations that fluctuate widely in abundance. Much of this fluctuation is due to variations in environmental factors which the community cannot avoid. However, genetically determined adaptations that have arisen through natural selection also play a part in determining the responses of a population to environmental fluctuations.

Further, the structure of community in which a population is found has a major role in determining the degree of environmental variability to which the species is subjected. There are at least two mechanisms by which community structure affects the stability or variability of a community. The first mechanism involves the relationship between community structure and microenvironment. Many organisms are protected from the full impact of environmental fluctuations because of the presence of other members of the community. For example, the floor of a conifer forest is protected from winds, evaporation, and temperature shifts, making it a much less harsh and variable environment for organisms than the forest canopy or an open field adjacent to the forest. The second mechanism by which community structure affects community stability is community diversity. But about the correlation of community stability and community diversity, many ecologists have expressed their doubts (**Hairston** *et al.*, 1968).

CORRELATION OF ENVIRONMENTAL GRADIENTS AND COMMUNITY GRADIENTS

Environmental units which afford uniform environmental conditions to the inhabiting species are called **biotopes.** The physical features of a biotope maintain the populations within the communities. In drastic environmental conditions the flora and fauna undergo abrupt changes and only those that are adapted to withstand the rapid variations are preferred by the environment. For example, in communities of littoral zone or of deserts, only those organisms that are typically adapted to withstand the environmental hazards can survive. Thus, different environmental factors (*e.g.*, temperature, rainfall, salinity, etc.) have a profound control over the populations so that habitats and communities vary along different environmental gradients or there is intergrading among them. For example, the gradual slope of land into the sea exhibits various grades of environmental factors and animal communities also correspondingly show a gradation from the shore through the intertidal zone to the deep sea region. Characteristic of an environmental gradient is a distinct zonation, each zone harbouring its own assemblage of species adapted to one another and giving way at a sharp boundary to another assemblage of species adapted to one another. For example the **elevation gradient** includes decreasing mean temperatures, decreasing lengths of growing seasons, increasing rainfall, increasing wind speeds, and so on, toward high elevation. All these factors act together on plants and animals. The assemblage of environmental factors that change together through the space along which a community gradient occurs and that influence its population may be termed as **complex-gradient** (see **Whittaker**. 1970). The environment gradient (complex gradient) and community gradient or **coenocline**, go hand in hand and both gradients collectively form the **ecocline**, the gradient of ecosystem. Gradient analysis of different ecoclines have revealed following trends and patterns :

1. Along a gradient from a "favourable" environment to an "extreme" environment there is normally a decrease in the productivity and massiveness of communities. The decrease in amount of organic matter per unit area is expressed in decrease of height of dominant organisms and percentage of the ground surface covered.

2. Towards increasingly unfavourable environments there is a stepping-down of community structure and a reduction of stratal differentiation, with generally smaller numbers of growth forms, (The different classes or kinds of forms of plants such as trees, lianas, shrubs, epiphytes, herbs and thallophytes are referred to as **growth-forms**) arranged in fewer and lower strata.

3. Some kinds of species-diversities of certain communities decrease from favourable to extreme environments, whether the latter are extremes of drought, or of cold, or of adverse soil chemistry or (for the sea cost) of tidal exposure.

4. Each growth-form has its characteristic place of maximum importance along the ecoclines—the rosette trees in some tropical forests, semishrubs in desert and adjacent semiarid communities, and so on. Some growth forms, for example, grasses and grass-like plants may have more than one area of importance along the major ecoclines.

5. Some growth-forms may be dominant in similar environments in widely different parts of the world. Thus, similar environments on different continents tend to have communities of similar physiognomy (study of form and structure in biotic or natural communities is called **physiognomy**). This adaptive convergence at the level of the community is one of the major generalizations about the geography of life.

ECOTONE AND EDGE EFFECT

In the ecocline, the line of demarcation (boundary-line) between two communities is often very difficult in view of the chances of overlapping of one community over another. Such demarcation will be conspicuous only when the dominants of the adjacent communities show clear and characteristic differences. The transition zone between two or more diverse communities is called the **ecotone**. The common examples of ecotone are following—the border between forest and grassland, the bank of a stream running through a meadow or between a soft bottom and hard bottom marine community. An ecotone thus, presents conditions that are intermediate to the communities which are on either side of it. The ecotones may be narrow or very wide, extending to large areas. The community on either side of the ecotone may have a typical structure, but the ecotone is strikingly different. The ecotone has a higher diversity than either of the main communities, a diversity that is not directly controlled by the climate or further fundamental environmental factors, but because of the migrations of individuals of different species-populations from both communities. Further, a number of special populations can become adapted specifically to the ecotone, even when both of the major communities are too simple or are otherwise unsuited for successful colonization by the species. This potential for the ecotone to act as habitat for species found in neither major community is termed the edge effect. A common example of the edge effect in action can be seen in those species of owl that live in or near ecotones between forests and grassland. They depend on forest trees for nesting, and they do their hunting in the grassland, where they depend on field rodents for food. In man-made communities such as agricultural fields, the transition zone (ecotone) between the field and the forest may act as a refuge for animal species formerly found in the plowed area, as well as for other plants such as weeds. Ecotones of this type are also the prime habitat of many species of insect, game bird, and mammal.

COMMUNICATION BETWEEN COMMUNITIES

It is impossible to draw a boundary line across which certain species do not naturally range. The shoreline, which would seem the most definitive of community boundaries, is regularly crossed by adult frogs, some insects, otters, beavers, snakes, shore birds, and muskrats, among other species. The range of several species of plants may include both sides of a shoreline. In addition, certain species, such as toads and many insects, spend their larval period in the water and their adulthood on land. Many large ungulates such as moose and deer have their summer range in one area and their winter range in another. Habitual passage from one community to another is the simplest type of communication between communities.

A second type communication involves two adjacent communities whose members seldom interact and tend to be restricted to one of the communities under normal conditions. But, under conditions of great stress in one ecosystem, such as forest fire, abnormal snowfall, certain kinds of intermittent pollution, and the like, animals can move temporarily into the other community, using as a refuge from which they can repopulate their own habitat after the stress conditions have passed. This type of interaction is characteristic of most communities that are subject to periodic catastrophe.

COMMUNITY STRATIFICATION

From structural point of view biotic communities exhibit vertical differentiation or stratification, horizontal differentiation and temporal differentiation (**Whittaker**, 1970). Stratification of biotic communities involve the formation of distinct strata or layers or storeys in vertical and horizontal plane by the organisms.

A. VERTICAL DIFFERENTIATION (STRATIFICATION OF COMMUNITY)

Most communities show vertical structure, differentiation or stratification—different species occur at different heights above the ground, or depths below the water surface. The species have different positions along a vertical gradient of depth in community and decreasing light intensity. Intensity of light necessarily decreases from the surface of the community, which is in full sunlight, downward ; light absorption by the organisms themselves is a principal reason for this extinction of light with depth. In a forest one may observe a several-storied physiognomy with a number of growth-forms (in each of which there may be a number of species) occurring one above the other to form the community's vertical structure.

Vertical stratification in plants : The forest trees with their upper foliage in full sunlight, form the **canopy** or uppermost level. The leaves and branch surfaces of the canopy trees may absorb and scatter more than half of the sunlight energy, but beneath the canopy there is a lower layer of smaller trees utilizing some of the remaining light. This lower tree stratum usually contains both younger individuals of the canopy tree species, and mature trees of other, smaller species that do not normally reach canopy height. Less than 10 per cent light reaching the upper canopy may penetrate through the tree foliage of both levels, and spectral composition of the remaining internal light of the forest is changed from that of sunlight. Species of a third level of vegetation, shrubs, are adapted in utilizing this weaker light within the forest, further reducing the light that reaches herbs beneath the shrub layer. The remaining light (1 to 5 per cent of incident sunlight) in many forests supports the growth of the herb layer. Beneath the herbs, mosses on the ground may form still another vegetation layer. In some dense forests only a fraction of 1 per cent of incident sunlight reaches the forest floor.

By reaching the canopy, the forest trees may gain advantage, where abundant sunlight supports photosynthesis, but the tree must spend much of the energy of photosynthesis in the growth of woody tissue of stem and branches to support the foliage in the canopy. There may be apparent disadvantages in the low light intensities in which the forest herbs must live, but the herbs need not spend its more modest photosynthetic profit on woody supporting tissue. Forest structure, thus, involves a gradient of growth-forms—upper and lower trees, upper and lower shrubs, upper and lower herbs, and soil-surface mosses—in adaptation to the gradient of light intensity. Along the gradient-growth-form designs change from one extreme (the upper tree with foliage in full sunlight, massive supporting stem and branch structure, and a root system smaller in mass than the above ground structure) to herbs with adaptations at the other extreme (photosynthesis at low levels of light intensity, small investment in above ground supporting structure, and accumulation of reserve food in a root system more massive than the above ground structure).

Vertical stratification in animals : Even as different plant species are adapted to different positions in this vertical gradient, so different animal species also occupy different levels in the forest. Different groups of bird species, for example, may be found feeding and nesting near the ground, in the shrub and small tree foliage beneath the canopy, and in the canopy itself. Different arthropod species occur at different levels from the canopy downward to the herb stratum and to and below the ground surface. A group of animals—mites and spring tails, millepedes and centipedes, ground beetles, and so on—occur primarily in the leaf litter on the soil surface ; these animals, which are seldom seen on the surface by daylight are called **cryptozoans**. Other animals occur at different depths in the soil, in which different plant species also have their roots extending to different depths.

Vertical stratification in plankton—In the plankton too there is a degree of vertical differentiation in the adaptation of different species to different levels and light intensities. Vertical movement affect the distribution of these species, however, and vertical differences in the community are less evident than in the forest. Communities of lighted zones below tide levels on the ocean floor show a differentiation determined in part by light intensities. Vertical differentiation is thus a common feature of many biotic communities.

B. HORIZONTAL STRATIFICATION OF COMMUNITY

Communities show horizontal differentiation (stratification), expressed in the patchy or mosaic-like occurrence of species, and in correlations of species that tend to occur separately in relation to the patches. Some plants appear to have even distribution, among them the shrubs in some deserts in which it is reasonable to suppose that it is less probable that one shrub will be close to another shrub of the same species (hence within the area of its root effects) than farther away from it. Singing birds. divide a community into territories, and each male of a species establishes and defends an area in which the pair nests and feeds ; these territories may be of the same order of size for all pairs of a given species in community. It seems clear that interaction among the birds has brought about a distribution that is more regular than random.

Departures from regular, even or random distribution toward positive contagion (**contagious** distribution refers to clumped distribution of a species) are very common in many kinds of communities. The plants of the forest floor are concentrated in patches, with few individuals between the patches. There may be following three basic causes of contagion of forest plants :

1. **Dispersal from parent plant :** Seeds from a plant may fall near that plant, producing when the seeds grow a clump of young plants. Plants spreading from a parent plant by runners or rhizomes may form clumps of individuals.
2. **Differences in environment :** The forest floor is a mosaic of patches receiving more light, or less, through the canopy. Light differences among these patches may influence the development of patches of herbs.
3. **Species interrelations :** One species may be dependent on another (for example, an herb parasitic on the roots of a tree species), or an herb population may be denser under trees of a given species because of the effects of the trees on the soil.

Animal populations too show varying degrees of contagion. Marine plankton animals and fish may be strongly clumped into schools. Most of the smaller animals of the forest show contagious distributions, with the degrees of contagion ranging up to the very strong contagion of ants in their colonies. Each species may have its own degree of clumping and spacing of clumps, different from the patterns of other species.

C. TEMPORAL DIFFERENTIATION OF COMMUNITY

Besides the differentiation of communities in space, there occur a differentiation of community in time also. Environments of biotic communities are rhythmic : in most environments light, temperature and other environmental factors go through daily and yearly cycles. In some communities, especially those of ocean shores, there are also complex rhythms set by the rise and fall of tides. In general, there occur rhythms of function in biotic communities in adaptation to rhythms of environment.

Plankton population fluctuate rapidly in many water bodies, with species replacing one another in periods of days and weeks. A number of major species may occur as plankton dominants in the course of the year. Thus in freshwater lake species of diatoms and other yellow-green algae may predominate in the winter plankton.

As water temperatures warm in later spring and early summer, these are replaced by desmids and other green algae. At peak summer temperatures blue-green algae may predominate or share dominance with the green algae ; as temperatures cool dominance shifts back toward the green and yellow-green algae. Each species has an inactive stage in which it survives the season unfavourable for its activity. Each species has its own place in the annual pattern, determined by its own response to the fluctuations of temperature and other environmental factors. The plankton community shows differentiation in time : different groups of species occur at different times during the seasonal cycle. The year-round total number of plankton species is much larger than the number present at a given time.

Seasonal and daily differentiation (stratification) occurs also in forests. One group of insects are active in the day time, another group at night, and a third group may be active in the twilight transitions of morning and evening. In terrestrial communities flycatchers, warblers, and other insectivorous birds are active by day, bat at night, and nighthawks in the dusk. Progress of the seasons is marked by the appearance of different groups of plants in flower and different groups of insects visiting these flowers. In deciduous forests spring beauties, dogtooth violets, and other herbs develop their foliage and flower early, before the trees are in leaf.

ALTERATION OF COMMUNITY PATTERNS IN TIME

Communities are not static ; they change. This change can be understood on several levels. The simplest is the growth, interaction and death of individual organisms as they pass through their life cycles, affected by the cycles of seasons and other natural phenomenon. But there are other levels of community change that act over longer time spans and that account for much larger changes in community composition and structure. These include **ecological succession**, the reaction of communities to alterations in fundamental regional abiotic factors, and community evolution.

ECOLOGICAL SUCCESSION

The replacement of one community by other kinds of communities in course of time due to changes in physical conditions is called **ecological succession** or **ecosystem development**. The ecological succession extends over a long time and is a gradual and continuous process which continues until a stable community called **climax community** is reached. The entire sequence of communities characteristic of a given region is termed a **sere** and the individual transitional communities are called **seral stages** or seral communities. Seres are sometimes classified according to the predominant force that is bringing them about. These forces are **biotic, climatic, physiographic,** and **geologic** and their resultant seres are commonly called **bioseres, cliseres, eoseres,** and **geoseres.** Further, there exist two major types of successional patterns—when succession starts from a barren area, such as bare rock or open water, it is called **primary succession**. But if an advanced successional stage retrogresses or is destroyed, the recovering successive stages leading toward a climax community represent **secondary succession.** The general theory underlying the concept of ecological succession defines a successional series from pioneer stage to the climax as a **xerosere**, if it starts from bare rock or soil, or as **hydrosere,** if it begins from open water. Varying numbers of seral stages are formed, and any relatively stable stage below the climax represents a **subclimax.** Further, in successive seral stages there is not only a change in the species of organisms present but an increase in the number of species and in the total biomass.

Thus, as a lake fills with silt it changes gradually from a deep to a shallow lake or pond, then to marsh, and beyond this, in some cases, to a dryland forest. When in an area of forest a farm field is abandoned, a series of plant communities grow up and replace one another—first annual weeds, then perennial weeds and grasses, then shrubs, and trees—until a forest ends the development. If a land slide exposes a surface of rock in the mountains, the surface may be successively occupied by sparse cover of lichens ; a spreading moss mat ; grasses, which enter and become a meadow ; a shrub thicket, which overtops and suppresses the grasses ; a first forest stage of smaller trees, which seed into the shrub thicket, grow through it and replace it ; and a final stage of larger trees, which take dominance from the first trees and may form a larger and potentially permanent forest community. All these processes of community development represent the simple cases of ecological succession.

According to **Whittaker** (1970) most ecological successions involves following characteristics :

1. There is usually progressive development of the soil, with increasing organic content, and increasing differentiation of layers or horizons toward the mature soil of the final community.

2. The height, massiveness, and differentiation into strata of the plant community increase.

3. Productivity, the rate of formation of organic matter per unit area in the community, increases with increasing development of the soil and of community, structure and increasing utilization by the community of environmental resources.

4. As height and density of above ground plant cover increase, the microclimate within the community is increasingly determined by characteristics of the community itself.

5. Species-diversity increases from the simple communities of early succession to the richer communities of late succession.

6. Populations rise and fall and replace one another along the time gradient in a manner much like that in stable communities along environmental gradients. The rate of this replacement in many cases slows through the course of succession as smaller and shorter-lived species are replaced by larger and longer-lived ones.

7. Relative stability of the communities consequently increases. Early stages are in some cases of instability, with populations rapidly replacing one another; the final community is usually stable, dominated by longer-lived plants, which maintain their populations with community composition no longer changing directionally.

Further, while primary succession is a long term phenomenon, secondary succession occurs quickly and proceeds rapidly. In the process of succession, the first community or organisms to become established are called **pioneer communities**. The successful species of a seral stage of succession often modify the environment resulting in a situation where in later successional species can stand up to the rigours of the competition. For example, changes in the communities of birds are regulated by the structure of vegetation, availability of perching sites, canopy height and structure, etc. By developing vegetation cover, modification of environment comes into effect and activity pattern of mosquitoes in different types of vegetation have been known considerably (**Haddlow**, 1961). In forest communities there exist post-sunset and pre-sunset peaks of activity, not met with in those living in banana plantations where the periodicity was much less marked.

Examples of ecological succession : One of the classic studies of ecological succession was made on the shores of Lake Michigan. As the lake has become smaller it has left successively younger sand dunes, and one can study the stages in ecological succession as one goes away from the lake. The youngest dunes nearest the lake, have only grasses and insects; the next older ones have shrubs such as cottonwoods, then evergreens and finally there is a beech-maple climax community, with deep rich soil full of earthworms and snails.

As the lake retreated it also left a series of ponds. The youngest of these ponds contain little rooted vegetation and lots of bass and blue-gills. Later the ponds become choked with vegetation and smaller in size as the basins fill. Finally the ponds become marshes and the marshes get transformed into a meadow with further addition of soil. Soon grasses grow, shrubs develop and later trees appear. Eventually, an aquatic plant community of the pond becomes transformed into a terrestrial forest community. Further, in this case of ecological succession, the aquatic animal community gets replaced in an orderly manner from purely fresh water forms through marsh inhabitants and meadow grazers to terrestrial dwelling forms.

Another dramatic example of community succession began August 7, 1883, when a volcanic explosion occurred on the Indonesian island Krakatoa, causing part of the island to disappear. The remainder was covered with hot volcanic debris to a depth of 60 meters and all life was obliterated. A year later some grass and a single spider were found. By 1908, 202 species of animals had taken up residence on the island. This increased to 621 species by 1919, and to 880 species by 1934, when there was a young forest on one part of the island.

Ecological succession can be demonstrated in the laboratory. If a few pieces of dry grass are placed in a beaker of pond water, a population of bacteria will appear in a few days. Next, flagellates appear and eat the bacteria, then ciliated protozoa such as paramecia appear and eat the flagellates. Finally predator protozoa such as *Didinium* will appear and eat the paramecia. The protozoa present as spores or cysts attached to the grass, emerge in a definite succession of protozoan communities.

The phenomenon of succession in animal communities has had far reaching implications of an applied nature, in particular in the fouling by sessile marine organisms (many tubicolous polychaetes, hydroids and barnacles) of the bottom of ships and piers. Seasonal progression and succession are two significant factors which affect the change in fouling complexes and concentration of larvae, certainly of attachment growth rate and longevity. According to **Daniel** (1954) and **A. Raja** (1959) the duration of breeding seasons govern seasonal progression and succession. Studies on the distribution and succession of sedentary organisms in the Madras harbour indicate that in one of the sites studied *Modiolus striatulus* and *Cynthia* sp. were the first to attach themselves to an unoccupied habitat. Barnacles appeared a month later with *Cynthia* and *Modiolus* until colonial ascidians like *Botryllus* and *Botrylloides* sps. and the bivalves *Mytilus viridis, Ostrea madrasensis* came on the scene. Activities of the barnacles were limited by the settlement of these forms and within a period of three months these fouling organisms reached the peak of complexity (see **Ananthakrishnan** and **Viswanathan**, 1976).

Climax : The community that ends a succession is termed a climax. The nature of the climax has been the subject of considerable debate. At one time it was believed that if an area were given sufficient time, all ecosystems would show succession to a single climax type controlled by the regional climate, regardless of the original surface upon which the ecological succession started or the composition of any of the intermediate stages. Acceptance of the doctrine of regional or climatic climax as the normal end point of succession is due largely to the work of **F. E. Clements** (1916), and a large terminology grew up to describe those stable communities that evidently represented the end points of succession but that were not climatic climaxes. Recent study, however, suggest that the natural variation of the abiotic environment, including local heterogeneity, more broad-scale topographic variations, and soil variation stemming from differences in the rocks from which the soils were formed are significant aspects of the environment, and that they are important enough that community differences related to them can always be expected. A useful review of the climax concept is given by **Whittaker** (1953). However, ecological succession is nondeterministic; it proceeds by the dynamic interaction of natural selection and the progressive changes in available niches without consideration of a "goal". Depending on the current state of the ecosystem, there may be several different paths by which succession can proceed at any time in a given area. Thus the species that can be incorporated into a developing community may be quite varied and may depend on chance as well as the array of environmental factors. It is difficult or impossible to predict the composition of the community in a given ecosystem at some time in the future, even if we can compare it with the pattern of succession in a similar ecosystem. Even slight differences in environmental conditions at some time during succession may lead to the establishment of different communities. If these community differences are reflected in different sorts of community environment interactions, there may be a divergence in succession, so that the climaxes are disimilar even though the regional climate is the same. Soil erosion and fire are the mechanisms by which community differences can result in the establishment of different climaxes under a single climatic regime.

Aceording to the **Whittaker** (1970), central phenomenon of the concept of climax is the community's relative stability. The populations of a climax community show some irregular fluctuations in time because of environmental change and the character of population process, and some climaxes show more regular or cyclic fluctuation. In the climax, however, there are fluctuations around a stable relatively constant, mean condition. Stability of the climax entails balances maintained in the function of a dynamic, living system.

For a species population in a climax community to be stable, there must be a balance between natality and mortality, between income of new individuals by reproduction and outgo (or spending) of individuals by death. Ideally, such balances of natality and mortality would, over longer periods at least, characterize all the species populations of the climax community. The balance is also applied to the intake and release of matter and energy by the community as a whole. This kind of constancy in the system, based on the balancing of income and outgo and superimposed on an underlying flow through the system, is known as a **dynamic equilibrium** or **steady state.** A pool along a stream examplified such state as in it water flows but with equal rates of inflow and outflow. The pool itself an object or system stays the same—in steady state. Climax, thus, implies a steady-state condition in a natural community.

COMMUNITY RETROGRESSION

It is in some cases possible to drive the successional process backwards by disturbing a community. A grassland under heavy grazing may show first a reduction in coverage of the plants most palatable to the cattle. With continued grazing the total grass coverage is reduced, the more palatable plant species disappear, and weeds that may be almost absent from the undisturbed grassland appear and spread with continued grazing and tampling, most of the grass may be destroyed and, despite the unpalatable weeds that survive, the soil is exposed to erosion. The end result of such community retrogression may be depending on the topographic position and soil, a mud field with erosion channels or a rocky mountain slope stripped of much of its soil. Thus by severe and continued disturbance all the trends of succession—soil development, community stature, productivity, diversity, stability, and extent of modification of environment by community—have been reversed toward zero.

COMMUNITY EVOLUTION

Like the responses of communities to changing abiotic conditions, community evolution involves progressive changes in climax communities. Because the evolution is exceedingly slow, it cannot be observed in operation, and few instances from the fossil record are sufficiently complete to show the process in action.

The example that best demonstrates evolution of the basic structure of the community is that of the development of a terrestrial community of a modern type by early reptiles some 250 million years ago. Between the time when vertebrates (amphibians) first became able to lead a predominant terrestrial existence some 350 million years ago and the establishment of an essentially modern type food web some 100 million years later, the structure of terrestrial community was decidedly different from what it is now. Development of the modern type of community structure required not only a complete rearrangement of the niche structure of the community but also the evolution of new species that could fill the new niches (**Olson**, 1961, 1966).

Attainment of the adaptations needed for terrestrial life by the first amphibians did not in itself establish a land-based vertebrate community. These early amphibians were carnivores, and the only animals inhabiting the land environment were insects. It is inconceivable that the clumsy locomotor system of early amphibians would have allowed them to prey effectively on animals such as insects. Thus the first communities inhabited by terrestrial vertebrates are best regarded as extensions of aquatic communities, with the land habit as an adaptation to improve the capabilities of organisms whose prime food supply was aquatic invertebrates and fish.

By some 300 million years ago, reptiles had evolved that could feed effectively on terrestrial invertebrates. An entirely land-based community was theoretically possible in which all herbivore niches were assumed by invertebrates and some of the carnivore niches by vertebrates. However, the palaeoecological evidences suggest that most contemporary carnivorous vertebrates were unable as yet to realize an entirely terrestrial carnivore niche, so that the great majority of the energy flow through the community continued to pass through the aquatic route. The typical food chain to the highest terrestrial vertebrate carnivore was plant→aquatic invertebrate→aquatic-invertebrate-feeding vertebrate→semi-aquatic predator→terrestrial predator.

By 250 million years ago terrestrial herbivorous vertebrates had evolved and a fully terrestrial vertebrates community could come into being. From this time onward the basic structure of the terrestrial community was of an essentially modern sort, with all consumer trophic levels occupied by a wide range of animals, both vertebrate and invertebrate.

Such evolutionary changes in the structure of communities are caused by a large number of factors. One factor is changes in the regional climate It was becoming progressively drier during the period under consideration, and the development of a land-based community reasonable response to this sort of change. Indeed many evolutionary changes in community structure can be explained on the basis of responses of major changes in the regional abiotic factors of the environment (**Axelrod**, 1950, 1958). But other chief factors of evolutionary change in community includes reorganization of the community's structure in response to the realization of niches that had not previously existed in the community.

CHAPTER 7

ECOSYSTEMS

The ecosystems are the basic functional ecological units which include both the organisms and the non-living environment, each influencing the properties of the other and both necessary for maintenance of life. They are complex self-sustaining natural systems which include all the interactions that bind their living and non-living components together into the stable systems. These interactions include those between organisms, the relationship between organisms and the physical environment, and the interactions of various phases of the non-living environment which mold its own change.

The word **ecosystem** was coined by **A. G. Tansley** (1935). The prefix *eco* means environment. A *system*, according to **Webster**, is "an aggregation or assemblage of objects joined in a regular interaction or interdependence." **Churchman** (1968) has defined a system as "a set of parts coordinated to accomplish a set of goals." The goal of a living system such as the tissues and organs that make up the animal body is a coordinated effort to cause a flow of energy through the system and thus maintain life. However, ecosystem is a very broad term and according to many ecologists (*e.g.*, **Smith**, 1974) it incorporates following aspects in it :

1. The ecosystem is a major ecological unit. It contains both abiotic (*e.g.*, water, soil, air, temperature, light, etc.) and biotic (*i.e.*, biotic communities) components through which nutrients are cycled and energy flows.

2. To accomplish those cycles and flows ecosystems possess a number of structural relationships between soil, water, nutrients, producers, consumers and decomposers.

3. The function of ecosystems is related to the flow of energy and the cycling of materials through the structural components of the ecosystem.

4. The total amount of energy that flows through a natural system depends upon the amount fixed by plants or producers. As energy is transferred from one feeding level to another, a considerable portion is lost for further transfer. This limits the number and mass of organisms that can be maintained at each feeding level.

5. Ecosystems tend toward maturity; in so doing they pass from a less complex to a more complex state. This directional change is called succession. Early stages of succession are characterized by an excess of potential energy and a relatively high energy flow per unit of biomass. In mature ecosystems there is less waste and less accumulation of energy because the energy flows through more diverse channels.

6. The major functional unit of the ecosystem is the population. It occupies a certain functional niche that is related to the population's role in energy flow and cycling of nutrients.

7. Both the environment and the amount of energy fixation in any given ecosystem are limited. When a population reaches the limits imposed by the ecosystem, its numbers must stabilize or failing this, decline (often sharply) from disease, strife, starvation, low reproduction and so on.

8. The ecosystem has historical aspects : the present is related to the past, and the future is related to the present.

9. The distribution of ecosystems on the earth is remarkably small in geographic extent when compared with the total volume of the earth. What we term the **biosphere** includes only tbe surface layer of solid ground or sediment beneath bodies of water, the oceans lakes and streams, and that portion of the atmosphere inhabited by flying or floating organisms such as birds, bats, and bacteria.

In preceding chapters we had a detailed discussions of different abiotic and biotic components of the ecosystems, and to avoid unnecessary repitition in this chapter, we will restrict our detailed discussion only to the flow of energy in ecosystems and also to biogeochemical cycles of the ecosystems.

COMPONENTS OF THE ECOSYSTEMS

Conventionally, the structural component of the ecosystems are studied from two standpoints. From the trophic (nourishment) standpoint, an ecosystem has two components : an **autotrophic** part, in which light energy is captured or "fixed" and used to synthesize complex organic compounds from simple inorganic ones, and a **heterotrophic** part, in which the complex molecules undergo rearrangement, utilization and decomposition. From structural point of view, however, it is convenient to recognize following four basic units in a pond ecosystem. **1. Abiotic substances**—These include basic inorganic and organic compounds of the environment. The inorganic components of the ecosystems are carbon dioxide, water, nitrogen, calcium, phosphate all of which are involved in material cycles (geochemical cycles). The organic components of the ecosystems are proteins, carbohydrates, lipids and amino acids, all of which are synthesized in the biotic phase. The climate, temperature, light and other physical factors are also normally included in abiotic components of the ecosystems. 2. **Producers**—producers of the ecosystems are the autotrophic organisms (mostly green plants) which can manufacture complex organic materials from simple inorganic substances. 3. **Macroconsumers** or **phagotrops**—The heterotrophic organisms (mostly animals) that ingest other organisms or chunks of organic matter. The **primary macroconsumers** (herbivores) feed on the plants and the **secondary macroconsumers** (carnivores) feed on the primary consumers. 4. **Microconsumres, saprotrophs** or **decomposers**—The saprotrophs are the heterotrophic organisms (mostly bacteria and fungi) which break down the complex compounds of dead organisms, absorb some of the decomposition products and release inorganic nutrients that are made available to the producers to complete the various cycles of elements. The producers,

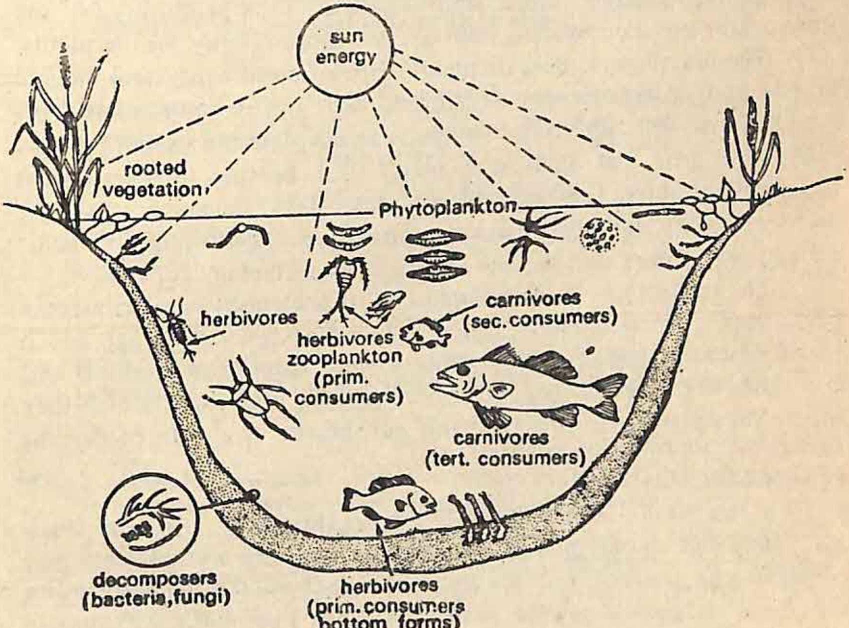


Fig. 7·1. A small fresh water pond as an example of an ecosystem. The component parts—producer, consumer and decomposer or reducer organisms, plus the non-living or abiotic components are indicated.

phagotrophs and saprotrophs, thus, make up the biomass of the ecosystem—the living weight.

EXAMPLE OF ECOSYSTEMS

A classic example of an ecosystem is a small lake or pond. (Fig. 7·1). The abiotic or non-living parts of a fresh water pond include the water, dissolved oxygen, carbon dioxide, inorganic salts such as phosphates, nitrates and chlorides of sodium, potassium, and calcium, and a multitude of organic compounds such as amino acids, humic acids, etc. The living part of the fresh water pond can be subdivided according to the functions of the organisms, *i.e.*, what they contribute toward keeping the ecosystem operating as a stable, interacting whole. In a fresh water pond there are two types of producers, the larger plants growing along the shore or floating in shallow water, and the microscopic floating plants, most of which are algae, that are distributed throughout the water as deep as light will penetrate. These tiny plants, collectively referred to as **phytoplankton**, are usually not visible unless they are present in great abundance and give the water a greenish tinge. Phytoplanktons have more significance as food producers for the fresh water pond ecosystem than are the more readily visible plants.

The macroconsumers or phagotrops of pond ecosystem include insects and insect larvae, crustacea, fish, and perhaps some fresh water clams. Primary consumers such as **zooplankton** (animal plankton) found near the surface of water and **benthos** (bottom forms) are the plant eaters (herbivores) and secondary consumers are the carnivores that eat the primary consumers. There might be some tertiary consumers that eat the carnivorous secondary consumers.

The ecosystem is completed by saprotrophs or decomposer organisms such as bacteria, flagellate protozoans and fungi, which break down the organic compounds of cells from dead producer and consumer organisms either into small organic molecules, which they utilize themselves, or into inorganic substances that can be used as raw materials by green plants.

FEED-BACK LOOP

Most interactions between living organisms, or between organisms and the abiotic phases of the ecosystem, are mutual ; activities of organisms are met by responses. The most common mechanism for these responses is the feed-back loop. Feed-back is extremely important in natural ecosystems, as it is the prime regulatory mechanism for the ecosystem as a whole and may affect both the rate and direction of whatever changes take place within it. **A feed-back loop** can be defined as the relationship in which a change in some original state of being "feeds back" onto that original state to alter the rate or direction of further change. There are two types of feed-back. In a **positive feed-back** relationship, the feed-back process leads to a self-sustaining change; in a **negative feed-back** relationship, the process maintains a dynamic homeostasis, or steady state. Thus positive feed-back relationships result in continual growth or decline of the entity in question, whereas negative feed-back results in a stabilization of the entity at some dynamic equilibrium.

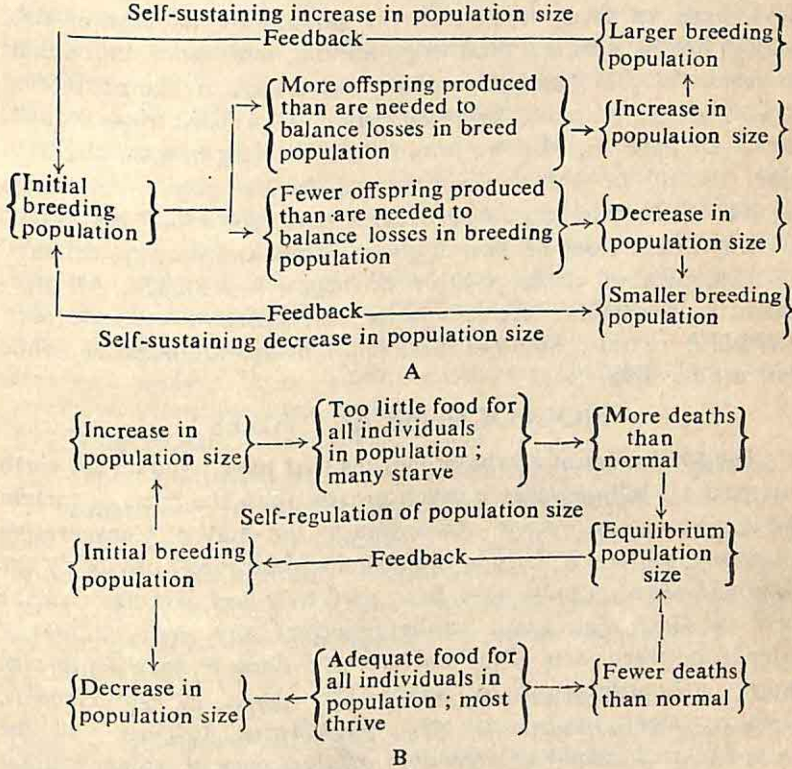

Self-sustaining increase in population size
Feedback
Larger breeding population
More offspring produced than are needed to balance losses in breed population
Increase in population size
Initial breeding population
Fewer offspring produced than are needed to balance losses in breeding population
Decrease in population size
Smaller breeding population
Feedback
Self-sustaining decrease in population size
A
Increase in population size
Too little food for all individuals in population ; many starve
More deaths than normal
Self-regulation of population size
Initial breeding population
Feedback
Equilibrium population size
Decrease in population size
Adequate food for all individuals in population ; most thrive
Fewer deaths than normal
B

Fig. 7·2. Generalized diagram of the operation of feedback mechanisms in natural ecosystems. Both figures refer to the operation of these mechanisms in the regulation of population size in a hypothetical population of animals : positive feedback leading to self-sustaining change (A), and negative feedback leading to self-regulated homeostasis (B).

Fig. 7·2 shows an example of positive and negative feedbacks. In both, we start with a given number of animals. In the positive feedback loop, production of a large number of offspring leads to a larger population than the original. This then becomes the new reproducing population, which can produce even more offspring. The result is a self-sustaining population increase, driven by the offspring feeding back into the breeding population. In the same way, if more breeders die than are replaced each year (which happens in some populations), this loss will be reflected in a smaller breeding population and will result in self-sustaining decline in population number by the same type of positive-feedback loop. In the negative feedback loop, the population is controlled by external factors, such as food supply. If the population increases in size, there will not be sufficient food to go around, and more individuals than usual will die from starvation ; conversely, if the population decreases in size, there will be more than enough food to go around, and the animals will be well-nourished, leading to a smaller than normal die off. In either case, the equilibrium population size is regained. Most interactions between different species of organisms, and many interactions between a given species and its physical environment depend on either positive or negative feedback. All organisms in an ecosystem are part of several different feedback locps at any point in time. Some of these relationships are negative, while others are positive.

BIOGEOCHEMICAL CYCLES

The total mass of all the organisms that have lived on the earth in the past 1·5 billion years is much greater than the mass of carbon and nitrogen atoms present. According to the **Law of Conservation of Matter**, matter is neither created nor destroyed ; obviously the carbon and nitrogen must have been used over and over again in the course of time. The earth neither receives any great amount of matter from other parts of the universe nor does it lose significant amounts of matter to outer space. The atoms of each element, carbon, hydrogen, oxygen, nitrogen, phosphorus, calcium and the rest, are taken from the environment, made a part of some cellular component of an organism and finally, perhaps by a quite circuitous route involving several other organisms, are returned to the environment to be used over again. The cyclic movements of chemical elements of the biosphere between the organism and the environment are referred to as **biogeochemical cycles**, after **Vernadskii** (1934). "Bio" refers to living organisms and 'geo' to the rocks, soil, air and water of the earth.

ORGANIC AND ABIOTIC PHASES OF GEOCHEMICAL CYCLES

Insofar as an element is necessary for the maintenance of life, its movement through biotic communities (organisms) can be viewed in the terms of food chain. The flow of a chemical element through the food chain can be viewed as the **organic phase** of the biogeochemical cycle. Further, the biogeochemical cycles also include **abiotic phases** which are the functions of the chemistry of the elements in question. These abiotic phases are of critical importance to the ecosystem, as the major reservoirs for all nutrient elements are external to the food chains, and flow in the abiotic phases tends to be much slower than in the organic phase. The rapidity and direction of nutrient cycling through the abiotic phases determine not only the distribution of the element in the total environment, but also its availability to living systems. There are two classes of abiotic phases in biogeochemical cycles, a **sedimentary phase**, which is part of all cycles, and an **atmospheric phase**, which is possessed by some. In some cycles, such as nitrogen, the atmospheric phase is more important than the sedimentary. In others, such as phosphorus, the atmospheric phase is essentially non-existent. In still others, such as sulphur, both phases are present and their relative importance depends on other environmental factors. Biogeochemical cycles that have dominant atmospheric phases are often called **atmosphere-reservoir cycles**; those whose sedimentary phase is dominant are termed **sediment-reservoir cycles.**

TYPES OF BIOGEOCHEMICAL CYCLES

There are two types of biogeochemical cycles, the **gaseous** and the **sedimentary**. In gaseous cycles the main reservoir of nutrients is the atmosphere and the ocean. In sedimentary cycles the main reservoir is the soil and the sedimentary and other rocks of the earth's crust. Both involve biotic and abiotic agents, both are driven by the flow of energy and both are tied to the **water cycle.**

A. WATER CYCLE

Living organisms, atmosphere and earth maintain between them a circulation of water and moisture, which is referred to as **water cycle** or **hydrologic cycle.** As we have already discussed in chapter 2, water forms a very significant factor of environment and without the cycling of water, biogeochemical cycles could not exist, ecosystems could not function, and life could not be maintained. Water is important for an ecosystem for several reasons—it is the medium by which nutrients are introduced into autotrophic plants; it is an important part of living tissue, either as liquid water or as part of essential organic molecules; it serves as a means of thermal regulation for both plants and animals; it is the medium by which sediments—a prime source of mineral nutrients—are removed from or added to local ecosystems; it covers the great majority of the earth's surface, and is the dominant feature of all aquatic ecosystems.

The hydrologic cycle is driven by solar energy and gravity. More than 80 per cent of the total insolation that is not lost immediately as electromagnetic radiation goes to **evaporate** water. The atmospheric water vapour producéd by this means can then condense around particles of dust in the atmosphere, often called **nucleation particles**. The atmosphere possesses a limited capacity for holding water vapour, thus, the droplets formed by this means are heavy enough to fall as precipitation under the influence of gravity. Eventually, the hydrologic cycle can be defined as an alternation of evaporation and precipitation, with the energy used to evaporate the water being dissipated as heat in the atmosphere as the water condenses.

Distribution of water in earth's surface : Water is not evenly distributed throughout the earth. Almost 95 per cent of the total water on earth is chemically bound into rocks and does not cycle. Of the remainder, about 97·3 per cent is in the ocean, about 2·1 per cent exists as ice in the polar caps and permanent glaciers, and the rest is fresh water, present in the form of atmospheric water vapour ground water, soil water, or inland surface water (**Nace**, 1967).

Table : Distribution of water in the earth's crust and surface (**Clapham, Jr.**, 1973).

A. Chemically bound water of rocks : Does not cycle	
1. Crystalline rocks	$250,000 \times 10^{17}$ Kg.
2. Sedimentary rocks	$2,100 \times 10^{17}$ Kg.
B. Free water : Moves via hydrologic cycle	
1. Oceans	$13,200 \times 10^{17}$ Kg.
2. Ice caps and glaciers	292×10^{17} Kg.
3. Ground water to a depth of 4000 m.	$83·5 \times 10^{17}$ Kg.
4. Fresh-water lakes	$1·25 \times 10^{17}$ Kg.
5. Saline lakes and inland seas	$1·04 \times 10^{17}$ Kg.
6. Soil moisture	$0·67 \times 10^{17}$ Kg.
7. Atmospheric water vapour	$0·13 \times 10^{17}$ Kg.
8. Rivers	$0·013 \times 10^{17}$ Kg.

The rate of cycling of water : The rate of cycling between surface and atmosphere is very rapid. The amount of water vapour in the atmosphere is sufficient, on the average, to cover the entire earth to a depth of 2·55 cm. But the average annual rainfall for the earth is about 81 1 cm (**Furon**, 1967) and in some places it ranges upto 1,200 cm. This means that the average turnover time for atmospheric water is about 11·4 days, or that the equivalent of all the water vapour in the entire atmosphere falls as precipitation and is re-evaporated more than 32 times per year.

Further, the distribution of evaporation and rainfall is quite uneven. If we compare the annual evaporation and precipitation over land and sea, we find that relatively more water precipitates on land than evaporates from land. This is fortunate from the point of view of terrestrial organisms. Even so, the amount of rainfall on the open ocean is proportionately greater than that on land, taking into account the relative percentages of the earth's surface covered by land and sea.

Nature of hydrologic cycles : The hydrologic cycles over the oceans is extremely simple—the water is evaporated from the surface of the ocean and water vapours form the clouds which when cool down precipitate the water as rain fall. But several routes are open to precipitation that falls on land—direct evaporation, transpiration, entery of water into ground water system and runoff. Consequently, the routes of hydrologic cycles on land can be divided into following three main categories—the rapidly cycling portion, or **evapotranspiration,** which includes the evaporation and transpiration, the less rapidly cycling water, or surface runoff, and very slowly cycling ground water that seeps into the soil can end up in any one of these three categories.

1. **Evapotranspiration :** Evapotranspiration includes evaporation and transpiration. **Evaporation** refers to water that is evaporated directly from any surface other than a plant, such as a lake, soil surface, or animal skin. In most cases, the main effects of direct evaporation are the moderate the temperature of local area and to allow the hydrologic cycle to continue. In some ecosystems, evaporation also leads to a concentration of salts in the water of soil which may be a critical environmental factor. **Transpiration** is water that evaporates from the surface of leaves of plants. Transpiration acts to move the biogeochemical cycles for all mineral nutrients that enter the food chain via the roots of plants.

2. **Surface runoff :** If transpiration is related to the mechanism of nutrient uptake, the gross movement of soluble and solid particles in the ecosystem is accomplished largely by runoff. Nutrients that have accumulated in sediments or soils can be eroded by streams and removed altogether from a local ecosystem, or soluble nutrients may be carried by soil. Seepage into surface waters, where they are removed from the area. Streams may carry sediment particles which can be chemically altered through additional weathering so that the nutrient elements they contain may be utilized by organisms. Finally

moving water acts as an agent of **erosion** which removes soil and allows weathering of the underlying rock to make their nutrients available to plants.

3. **Ground water :** Ground water is water that saturates either sediment or rock below the water table. In general, it is not tapped by plants for transpiration and it is too deep to be directly evaporated from the soil surface. It is an exceedingly important reservoir for water which moves from one place to another under the influence of gravity. The area where the net water movement is from the surface into the ground water systems is termed a **catcument area** ; areas where ground water reaches the surface and runs off are termed **springs.** A rock body through which ground water flows is called an **aquifer.** A well drilled into an aquifer that has sufficient hydrostatic pressure to force water up into it is called an **artesian well.**

The hydrologic cycle on land thus includes evapotranspiration of water from earth's surface and leaf surface→formation of clouds →precipitation→surface runoff+accumulation of water as ground water→return of water to sea via streams or direct evaporation and cloud formation, and so on.

B. GASEOUS CYCLES

The gaseous geochemical cycles are of following types :

1. **The oxygen cycle :** Oxygen (O_2), the by-product of photosynthesis, is involved in the oxidation of carbohydrates with release of energy, carbondioxide and water. Its primary role in biological oxidation is that of a hydrogen acceptor. The break-down and decomposition of organic molecules proceeds primarily by dehydrogenation. Hydrogen is removed by enzymatic activity from organic molecules in a series of reactions and is finally accepted by the oxygen, forming water. Though oxygen is necessary for life, but being very active chemically, molecular O_2 may be toxing to living body cells. Therefore, for the protection from toxic effects of molecular O_2, cells possess the cellular organelles called **peroxisomes** which mediate oxidative reactions resulting in the production of hydrogen peroxide which in turn is used through the mediation of other enzymes as an acceptor in oxidizing other compounds.

The major supply of free oxygen which supports life occurs in the atmosphere. There are two significant sources of atmospheric oxygen. One is the **photodisassociation** of water vapour in which most of the hydrogen released escapes into outer space. The other source is **photosynthesis,** active only since life began on earth. Because photosynthesis and respiration are cyclic, involving both the release and utilization of oxygen, one would seem to balance the other, and no significant quantity of oxygen would accumulate in the atmosphere. However, at some time in the earth's history the amount of oxygen introduced into the atmosphere had to exceed the amount used in the decay of organic matter and that tied up in the oxidation of sedimentary rocks. Part of the atmospheric oxygen represents that portion remaining from the unoxidized reserves of photosynthesis—coal, oil, gas, and organic carbon in sedimentary rocks. The amount of stored carbon in the earth suggests that 150×10^{20}g of oxygen has been available to the atmosphere, over 10 times as much as now present, 10×10^{20}g (**Johnson**, 1970). The main non-living (abiotic) oxygen pool consists of molecular oxygen, water, and carbon dioxide, all intimately linked to each other in photosynthesis and other oxidation-reduction reactions, and all exchanging oxygen with each other. Oxygen is also biologically exchangeable in such compounds as nitrates and sulfates utilized by organisms that reduce them to ammonia and hyrogen sulfide.

The cycling of oxygen is very complex. As a constituent of CO_2, it circulates freely throughout the biosphere. Some carbon dioxide combines with calcium to form carbonates. Oxygen combines with nitrogen compounds to form nitrates, with iron to ferric oxides, and with many other minerals to form various other oxides. In these states oxygen is temporarily withdrawn from circulation. In photosynthesis the oxygen freed is split from the water molecule. This oxygen is then reconstituted into water during plant and animal respiration. Some part of the atmospheric oxygen that reaches the higher levels of the toposphere is reduced to ozone (O_3) by high-energy ultravoilet radiation.

2. **The carbon cycle :** The carbon being a basic constituent of all organic compounds and a major element involved in the fixation of energy by photosynthesis, is so closely tied to energy flow that the two are inseparable. The source of all the fixed carbon both in living organisms and fossil deposits is carbon dioxide, CO_2, found in the atmosphere and dissolved in the waters of the earth. During photosynthesis, carbon from atmospheric CO_2 is incorporated into the production of the carbohydrate, glucose, $C_6H_{12}O_6$, that subsequently may be converted to other organic compounds such as polysaccharides (sucrose, starch, cellulose, etc.), proteins and lipids. All the polymeric organic compounds containing carbon are stored in different plant-tissues as food and from them the carbon is passed on to the trophic levels of herbivores or phyto-parasites, or retained by the plant until it serves as food for decay organisms (*viz.*, decomposers). Some of the carbon is returned to the atmosphere

(or the enveloping aqueous medium) in the form of CO_2, a by-product of plant respiration, in which, a considerable portion of glucose is oxidized to yield CO_2, H_2O and energy as follows :

$$\tfrac{1}{6}C_6H_{12}O_6+O_2 \rightarrow CO_2+H_2O+\text{Energy}$$

The CO_2 which is released as the by-product of plant respiration is again used by plants in photosynthesis. This is the basic carbon cycle which is simple and complete. Decomposing micro-organisms are important in breaking down dead material with the release of carbon back into the carbon cycle.

Similarly, carbon taken up by herbivores. or photoparasites may travel a number of routes. It may be incorporated into protoplasm (assimilation) and stored until the organism dies, where upon it is utilized by decomposers; it may be released through animal respiration; it may serve as live food for other organisms; or finally it may be stored in the environment as CO_2. Similar fates awaits carbon at the carnivore trophic levels. In fact, all the carbon of plants, herbivores, carnivores and decomposers is not respired but some is fermented and some is stored. The carbon compounds that are lost to the food chain after fermentation, such as methane, are readily oxidized to carbon dioxide by inorganic reactions in the atmosphere. As for the storage of carbon in sediments, just as deposition works to store materials, erosion may uncover them, and inorganic chemical weathering of rock can oxidize the carbon contained there. Some carbon is permanently stored in sediments and not uncovered by weathering; it may be replaced by carbon dioxide released from volcanoes and other similar examples of intense geological activity. In modern age man has greatly increased the rate at which carbon is passing from sedimentary form to carbon dioxide. The combustion of fossil fuels is a significant means of recycling sedimentary carbon much faster than natural weathering.

Small portion of carbon, espacially in the sea, is found not as organically fixed carbon, but as carbonate ($CO_3^{=}$), especially calcium carbonate ($CaCO_3$). $CaCO_3$ is very commonly used for shell construction by such animals as clams, oysters, some protozoa, and some algae. Carbon dioxide reacts with water to form carbonate in the following three step reaction :

$$CO_2+H_2O \rightleftarrows \underset{\text{Carbonic acid}}{H_2CO_3} \rightleftarrows \underset{\text{Bicarbonate}}{H^{+}+HCO_3^{-}} \rightleftarrows \underset{\text{Carbonate}}{2H^{+}+CO_3^{=}}$$

The precise amount of each of these constituents in the water depends on the pH of the water. Organisms such as clams can combine bicarbonate or carbonate with calcium dissolved in the water to produce calcium carbonate. After the death of the animal, this calcium carbonate may either dissolve or remain in sedimentary form.

Certain control mechanisms are inherent in the carbon cycle. The rate of carbon utilization is dependent on its availability. If excessive amounts of carbon are taken up in any one phase of the cycle, other phases of activity may be inhibited or slowed down. For example, if the pH of water is alkaline, more carbon is tied up in a carbonate and less is in solution. This removal of carbon in solution would upset the equilibrium established between the atmospheric and the dissolved CO_2 and the net effect would be a movement of CO_2 into solution until equilibrium was reached.

Peculiarities of carbon-cycle : Though carbon-cycle exhibits basic similarity with other biogeochemical cycles, yet it is unusual in that the organic phase is not essentially a complete cycle within itself. The organic (biotic) and atmospheric (abiotic) phases, however, are so closely intertwined that the rapid cycling typical of the organic phase is present. The multiplicity of paths along which carbon can flow is typical of biogeochemical cycles in general, and provides a well-buffered system with adequate feedback mechanisms to insure an adequate supply of the carbon. It is significant that all phases of the cycle yield carbon dioxide at some time, and carbon dioxide is the raw material for them. Thus, despite its relative low concentration in the atmosphere (0·03 per cent), carbon in a form in which it can be used by living organisms is virtually always present.

3. The nitrogen cycle : Nitrogen is an essential constituent of different biologically significant organic molecules such as amino acids and proteins, pigments, nucleic acids and vitamins. It is also the major constituent of the atmosphere, comprising about 79 per cent of it. The paradox is that in its gaseous state, N_2, abundant though it is, nitrogen is unavailable to most life. Before it can be utilized it must be converted to some chemically usable form.

To be used biologically, the free molecular nitrogen has to be fixed and fixation requires an input of energy. In the first step molecular nitrogen, N_2, has to be split into two atoms : $N_2 \rightarrow 2N$. The free nitrogen atoms then must be combined with hydrogen to form ammonia, with the release of some energy :

$$2N + 3H_2 \rightarrow 2NH_3$$

This fixation comes about in two ways. One is by high-energy fixation such as cosmic radiation, meteorite trails, and lightning that provide the high energy needed to combine nitrogen with oxgen and hydrogen of water. The resulting ammonia and nitrates are carried to the earth in rain water. The second method of nitrogen-fixation which contributes about 90 per cent of fixed nitrogen of earth, is biological. Some bacteria, fungi, and blue-green algae can extract molecular nitrogen from the atmosphere and combine it with hydrogen to form ammonia. Some of this ammonia is excreted by the nitrogen-fixing organism, and thus becomes directly available to other autotrophs. Some of these nitrogen-fixing organism may be free-living, either in the soil (*e.g.*, bacteria-*Azobacter* and *Clostridium*) or in water (*e.g* , blue-green algae-*Nostoc*, *Calothrix* and *Anabaena*) and produce vast quantities of fixed nitrogen. In other cases, certain symbiotic bacteria of genus *Rhizobium*, although unable to fix atmospheric nitrogen themselves, can do this when in combination with cells either from the roots of legumes (*e.g.*, peas, beans, clover and alfalfa) and of other angiosperms such as *Alnus*, *Ceanothus*, *Shepherdia*, *Elaeagnus* and *Myrica*, or from the leaves of African genera of *Rubiaceae* and *Pavetta*. The bacteria invade the roots or leaves and stimulate the formation of root-nodules or leaf-nodules, a sort of harmless tumor. The combination of symbiotic bacteria and host cells remains able to fix atmospheric nitrogen and for this reason legumes are often planted to restore soil fertility by increasing the content of fixed nitrogen. Nodule bacteria may fix as much as 50 to 100 kilograms of nitrogen per acre per year, and free soil bacteria as much as 12 kilograms per acre per year. Further both free soil bacteria (*Azobacter*, and *Clostridium*) produce ammonia as the first stable product and like the symbiotic bacteria, they require molybdenum as an activator and are inhibited by an accumulation of nitrates and ammonia in soil.

Recently, certain lichens (*Collema tunaeforme* and *Peltigera rufescens*) were also implicated in nitrogen fixation (**Henriksson, 1971**). Lichens with nitrogen-fixing ability possess nitrogen-fixing blue green species as their algal component.

Nitrogen fixed by symbiotic and non-symbiotic micro-organisms in soil and water is one source of nitrogen. Another source is organic matter. The nitrogenous wastes and carrion of animals are degraded by the detritus organisms, nitrogen is converted to the amino form (*e.g.*, L-Alanine). The amino group ($-NH_2$) is liberated from the organic molecules to form ammonia ; this process is called **deamination**. Certain specific bacteria, most notably of the genus *Nitrosomonas*, can oxidize ammonia to nitrite (NO_2) by the reaction.

$$2NH_3+3O_2 \rightarrow 2NO_2^-+2H_2O+2H^+$$

This reaction takes place in the soil, in lake or sea water or sediments, and whenever ammonia is being released and oxygen is present. As fast as nitrite is produced, other bacteria, such as

Nitrobacter, can combine nitrite with oxygen to form nitrate (NO_3) by the reaction :

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Both of these reactions which are performed by two nitrifying bacteria—*Nitrosomonas* and *Nitrobacter* are the parts of a single biological process called **nitrification**. In nitrification process, thus, ammonia is oxidized to nitrate and nitrite yielding energy. This energy is used by the bacteria to make their organic materials directly from carbon dioxide and water. Nitrate can be taken up by autotrophs at the beginning of food chain.

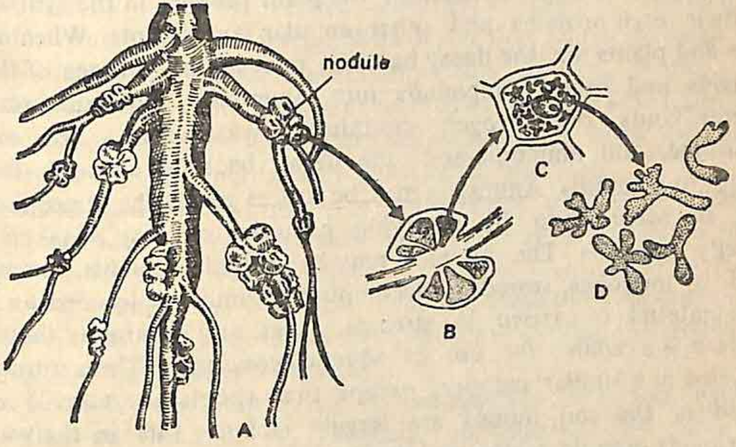


Fig. 7·3. Root-nodules of a legume plant. A—Legume root with root nodules B—T.S. of root nodule. C—Single cell of nodule, D—Nitrogen-fixing bacterium, *Rhizobuim*.

Under certain circumstances, nitrate is either not produced in the nitrogen cycle or it is degraded before it can be utilized by autotrophs. Degradation of nitrate is called **denitrification**, and may be important when oxygen concentration is low. Denitrifying bacteria such as *Pseudomonas* can use the energy of the nitrate ion to drive their metabolism, and in so doing, they break the nitrate down to nitrite, ammonia, or molecular nitrogen :

$$C_6H_{12}O_6 + 12NO_3^- \rightarrow 12NO_2 + 6CO_2 + 6H_2O$$

$$C_6H_{12}O_6 + 8NO_2 \rightarrow 4N_2 + 2CO_2 + 4CO_3^= + 6H_2O$$

$$C_6H_{12}O_6 + 3NO_3 \rightarrow 3NH_3 + 6CO_2 + 3OH^-$$

If denitrification is significant in an ecosystem nitrite is transitory and is also degraded into either ammonia or molecular nitrogen.

Cycling of nitrogen in the ecosystems : The sources of inputs of nitrogen under natural conditions are the bacterial fixation of atmospheric nitrogen, addition of inorganic nitrogen in rain from such sources as lightning fixation and fixed "juvenile" nitrogen from volcanic activities, ammonia absorption from the atmosphere by plants and soil, and nitrogen accretion from windblown aerosols, which contain both organic and inorganic forms of nitrogen. In terrestrial ecosystems, nitrogen, largely in the form of ammonia and nitrates is taken up by plants, which convert it into amino acids and proteins. Animals (primary macro-consumers) may eat the plants and utilize the amino acids from the plant proteins in the synthesis of their own proteins and other cellular constituents. When animals and plants die, the decay bacteria convert the nitrogen of their proteins and other compounds into ammonia. Animals excrete several kinds of nitrogen—containing wastes-urea, uric acid, creatinine, and ammonia-and the decay bacteria converts these wastes to ammonia. Ammonia may be lost as gas to the atmosphere, may be acted upon by nitrifying bacteria, or may be taken up directly by plants. The nitrates may be utilized by plants, immobilized by microbes, stored in decomposing humus, or leached away. This material is carried to streams, lakes, and eventually the sea, where it is available for use in aquatic ecosystems. There nitrogen is cycled in a similar manner, except that the large reserves contained in the soil humus are largely lacking. Life in the water contributes organic matter and dead organisms that undergo deposition and subsequent release of ammonia and ultimately nitrates. In aquatic ecosystem atmospheric nitrogen is fixed by numerous blue-green algae.

Under natural conditions nitrogen lost from ecosystems by denitrification, volatilization, leaching, erosion. wind blown aerosols, and transportation out of the system is balanced by biological fixation and other sources. Both chemically and biologically, terrestrial and aquatic ecosystems constitute a dynamic equilibrium system in which a change in one phase affects the other.

Comparison of nitrogen-cycle and carbon-cycle : A comparison of the nitrogen and carbon cycles points out some obvious differences between them. Although the atmospheric phase clearly constitutes the main reservoir for both elements in the total environment, atmospheric nitrogen exists in a very different form from that in which it is taken up by autotrophs. But it constitutes a source from which losses sustained by the organic phase can be made up. Also, there are more inorganic chemical reactions external to the food chain in the nitrogen cycle than in the carbon cycle. Despite these differences, both the nitrogen and carbon cycles are examples of finely tuned circuits which meet demands for the needed elements through several pathways, each controlled by effective self-regulating feedback loop.

C. SEDIMENTARY CYCLES

Mineral elements required by living organisms are obtained initially from inorganic sources. Available forms occur as salts dissolved in soil water or lakes, streams, and seas. The **mineral cycle** varies from one element to another, but essentially it consists of two phases ; the **salt-solution phase** and the **rock phase**. Mineral salts come directly from the earth's crust by weathering. The soluble salts then enter the water-cycle. With water they move through the soil to streams and lakes and eventually reach the sea, where they remain indefinitely. Other salts are returned to the earth's crust through sedimentation. They become incorporated into salt beds, silts and limestones; after weathering they again enter the cycle.

Plants and animals, the living components of the ecosystems, fulfil their mineral requirements from mineral solutions in their environments. Other animals aquire the bulk of their minerals from plants and animals they consume. After the death of living organisms the minerals are returned to the soil and water through the action of the organisms and process of decay.

There are different kinds of sedimentary or mineral cycles, depending on the kinds of elements, but following two cycles are very significant for a ecosystem :

(i) **Sulfur cycle** : Sulfur, like nitrogen, is an essential part of protein and amino acids and is characteristic of organic compounds. It exists in a number of states—elemental sulfur, S, sulfides, sulfur monoxide, sulfite, sulfates. Of these the three are important in nature are elemental sulfur, sulfides and sulfates.

The sulfur cycle is both sedimentary and gaseous (*i.e.*, it includes gaseous phase and sedimentary phase). The sedimentary phase of sulfur cycle is long-termed and in it sulfur is tied up in organic and inorganic deposits. From these deposits, it is released by weathering and decomposition, and is carried to terrestrial and aquatic ecosystems in a salt solution. Atmospheric (gaseous) phase of sulfur-cycle is less pronounced and it permits circulation on a global scale.

Sulfur enters the atmosphere from several sources—the combustion of fossil fuels, volcanic eruption, the surface of the oceans and gases released by decomposition. Intially sulfur enters the atmosphere as hydrogen sulfide, H_2S, which quickly oxidizes into another volatile form, sulfur dioxide, SO_2. Atmospheric sulfur dioxide, soluble in water, is carried back to earth in rainwater as weak sulfuric acid, H_2SO_4. Whatever its source, sulfur in a soluble form, mostly as sulfate ($SO_4^{=}$) is absorbed through plant roots, where it is incorporated into certain organic molecules, such as some amino acids (*e.g.*, cystine) and proteins. From the producers the sulfur in amino acids is transferred to the consumer animals, with excess being excreted in the feces.

Excretion and death carry sulfur in living material back to the soil and to the bottoms of ponds, lakes, and seas where the organic material is acted upon by bacteria of detritus food. Chain within the detritus food chain, the sulfhydryl group (—SH) of amino acids (*e.g.*, L-cysteine) is separated from the rest of the molecule as hydrogen sulfide (H_2S) by most decomposing bacteria as a normal part of the degradation of proteins. In an aerobic environment, the hydrogen sulfide is oxidized to sulfate by bacteria specially adapted to perform this conversion :

$$H_2S+2O_2 \rightarrow SO_4^{=}+2H^+$$

The sulfate produced then can be reused by the autotrophs. In anaerobic environments, such as bottom of certain lakes, it is impossible to oxidize sulfide by this means, because the process of oxidation requires oxygen. But if infrared radiation is present in these environments, there are photosynthetic bacteria that can use it to manufacture carbohydrates and oxidize sulfide either to elemental sulfur or sulfate :

$$6CO_2+12H_2S+hv \rightarrow C_6H_{12}O_6+H_2O+12S$$
$$6CO_2+12H_2O+3H_2S+hv \rightarrow C_6H_{12}O_6+6H_2O+3SO_4^{=}+6H^+$$

Elemental sulfur can also be utilized by other bacteria to form sulfate. If oxygen is present, the reaction is quite rapid.

$$2S+3O_2+2H_2O \rightarrow 2SO_4^{=}+4H^+$$

Under anerobic conditions, elemental sulfur can still be oxidized to sulfate by certain bacteria if nitrate is present :

$$6NO_3^-+5S+2CaCO_3 \rightarrow 3SO_4^{=}+2CaSO_4+2CO_2+3N_2$$

None of these bacterial reactions is unidirectional; under certain conditions, sulfate can also be reduced either to sulfide or to elemental sulfur by bacteria. This series of reactions operating within the organic phase of the sulfur cycle provides a rather finely tuned mechanism for regulating the availability of sulfur to autotrophs.

The sulfur is removed from the organic phase in the form of elemental sulfur which is unsoluble and accumulates in sediments. If iron is present in the sediment, it can combine with sulfide to form iron sulfides, all of which are highly insoluble :

$$Fe^{++}+S^{=} \rightarrow FeS$$

Fe(ionic)+2S(ionic) → FeS_2 (Ferrous sulfide or pyrite)

FeS_2 is highly insoluble under neutral and alkaline conditions and is firmly held in mud and wet soil. Some ferrous sulfide is contained in sedimentary rocks overlying coal deposits. Exposed to the air in deep and surface mining, the ferrous sulfide oxidizes and in the presence of water produces ferrous sulfate and sulfuric acid :

$$2FeS_2+7O_2+2H_2O \rightarrow 2FeSO_4+2H_2SO_4$$

$$12FeSO_4+3O_2+6H_2O \rightarrow 4Fe_2(SO_4)_3+4Fe(OH_3)\downarrow$$

In this manner sulfur in pyritic rocks, suddenly exposed to weathering by man, discharges heavy slugs of sulfur, sulfuric acid, ferric sulfate and ferrous hydroxide into aquatic ecosystems. These compounds destroy aquatic life and cause acidic water.

(ii) **Phosphorus cycle :** Phosphorus cycle has no atmospheric phase. It occurs naturally in environment as phosphate (PO_4^-, or one of its analogues, HPO_4^- or $H_2PO_4^-$), either as soluble inorganic phosphate ions, as soluble organic phosphate (*i.e.*, as a part of a soluble organic molecule), as particulate phosphate (*i.e.*, as part of an insoluble organic or inorganic molecules) or as mineral phosphate (*i.e.*, as part of a mineral grain as found in a rock or sediment). The ultimate source of phosphate in the ecosystem is crystalline rocks. As these are eroded and weathered, phosphate is made available to living organisms, generally as ionic phosphate. This is introduced into autotrophic plants through their roots, where it is incorporated into living tissues. From autotrophs, it is passed along the grazing food chain in the same fashion as nitrogen and sulfur, with excess phosphate being excreted in the faeces. An extreme example of faecal phosphate is the tremandous guano deposits built up by birds on the desert west coast of South America. Phosphates can also be released as particulate matter from forest and grassland fires.

In the detritus food chain, as large organic molecules containing phosphates are degraded, the phosphate is liberated as inorganic ionic phosphate. In this form it can be immediately be taken up by autotrophs, or it can be incorporated into a sediment particle, either in the soil of a terrestrial ecosystem or in a sediment of an aquatic ecosystem. The sedimentary phase of phosphorous cycle remains comparatively slow than the organic phase.

Besides phosphorus, there are biogeochemical cycles for all the other nutrients (minerals) used by living organisms, as well as some that are not. Most of them has complete cycles in sedimentary phase. Their availability depends on their solubility in water and availability of water as solvent.

Thus, the geochemical cycles of different chemical substances are closed : the atoms are used over and over again. To keep the cycles going does not require new matter but it does require **energy**, for the energy cycle is not a closed one. Further, the patterns of flow, both of energy and of chemical substances, are of great significance. The simpler patterns involves energy, as the sources of energy are external to the ecosystem, and flow is unidirectional through it. Chemical substances, on the other hand, are finite and have their origin inside the ecosystem; thus they must continnously cycle within the system.

ENERGY FLOW IN ECOSYSTEMS

Energy can be defined as the capacity to do work, whether that work be on a gross scale as raising mountains and moving air masses over continents, or on a small scale such as transmitting a nerve impulse from one cell to another. There are two kinds of energy, **potential** and **kinetic**. Potential energy is energy at rest. It is capable of and available for work. Kinetic energy is due to motion, and results in work. Work that results from the expenditure of energy can both store energy (as potential energy) and arrange or order matter without storing energy.

The expenditure and storage of energy is described by two laws of thermodynamics. The first law of thermodynamics, called **law of conservation of energy** states that *energy is neither created nor destroyed.* It may change forms, pass from one place to another, or act upon matter in various ways, but regardless of what transfers and transformations take place, no gain or loss in total energy occurs. Energy is simply transferred from one form or place to another. When wood is burned the potential energy present in the molecules of wood equals the kinetic energy released, and heat is evolved to the surroundings. This is an **exothermic reaction**. In **endothermic reaction**, energy from the surrounding may be paid into a reaction For example, in photosynthesis, the molecules of the products store more energy then the reactants. The extra energy is acquired from the sunlight, but even than there is no gain or loss in total energy. Further though the total amount of energy involved in any chemical reaction, such as burning wood, does not increase or decrease, much of the potential energy stored in the substance undergoing reaction is degraded during the reaction into a form incapable of doing any further work. This energy ends up as heat serving to disorganize or randomly disperse the molecules involved, thus making them useless for further work. The measure of this relative disorder is named **entropy**.

The second law of thermodynamics states that whenever energy is transformed from one kind to another, there is an increase in entropy and a decrease in the amount of useful energy. Thus, when coal is burned in a boiler to produce steam, some of the energy creates steam that performs work, but part of the energy is dispersed as heat to the surrounding air. The same thing happens to energy in the ecosystem. As energy is transformed from one organism to another in the form of food, a large part of that energy is degraded as heat and as a net increase in the disorder of energy. The remainder is stored in living tissue.

Three sources of energy account for virtually all the work of the ecosystem : gravitation, internal forces within the earth and solar radiation. The last is very significant for ecosystem. The solar radiations which originate from sun is the source of energy for life and life is what sets the ecosystem apart from other natural systems.

ENERGY IN AN ECOSYSTEM

Living organisms can use energy in several forms, but all can be grouped under one of two headings : **radiant** and **fixed**. Radiant energy is in the form of electromagnetic waves such as light. Fixed energy is potential chemical energy bound up in various organic substances which can be broken down or reacted with something else in order to release their energy content.

Only a small fraction of the light energy reaching the earth is trapped ; considerable areas of the earth have no plants, and plants can utilize in photosynthesis only about 3 per cent of the incident energy. This radiant energy of sun is converted into chemical or potential energy by photosynthesis in plants the **photosynthetic autotrophs :**

$$6CO_2 + 6H_2O + hv \rightarrow 6C_6H_{12}O_6 + 6O_2$$

CO_2 from atmosphere	water from soil	light energy	sugar in plant cell	Oxgen released to atmosphere.

The reaction is catalyzed by certain pigments (*e.g.*, chlorophylls) in the cells. The product of this reaction is carbohydrate such as sugar (glucose) shown above. This sugar can have several destinations : it can be converted to a relatively inert energy-rich organic substance such as starch, and stored ; it can be combined with other sugar molecules to form specialized carbohydrates such as cellulose, which are used by the plants for specific purposes ; and it can be combined with other substances—such as nutrient substances such as nitrogen, phosphorus, and sulfur, to build complex molecules like proteins, nucleic acids, pigments and hormones. All these types of reactions are necessary for normal growth and maintenance of body tissues and functions of the plants. All required energy which is provided by oxidation of some of the sugar produced by photosynthesis to give CO_2, H_2O and usable chemical energy :

$$C_6H_{12}O_6+6O_2\rightarrow 6CO_2+6H_2O+\text{ usable energy}$$

Oxidation of sugar or any other organic molecule to get usable energy by organism is called **respiration**. The energy released by respiration is lost permanently to the ecosystem.

Primary production : All the energy that the plant actually fixes results in the formation of sugar. Conversely, all the sugar produced in the leaves of green plants is derived from carbon dioxide and water which have been combined by the solar energy. Thus, one can speak of the energy incorporated into living tissue either in terms of the light energy utilized or in terms of the sugar produced. Because all the energy used by the plant is converted into chemical energy, it should theoretically be possible to determine the entire energy uptake of plants by measuring the total amount of sugar produced. This quantity is termed **gross primary production** or **gross productivity**. Because, it is not easy to measure gross primary production in most ecosystems because some of the sugar produced by photosynthesis is lost immediately through respiration. So, if one measures the total organic material actually present in the plant (*i.e.*, biomass), then indirectly he will measure the gross primary production less the respiration, or **net primary production.** In addition, there are direct measurement techniques involving the rate of uptake of radioactive carbon ^{14}C. Productivity is generally expressed in terms of grams or kilocalories per sq metre per day or per year. It can also be expressed as $P_g=P_n+R$, where P_g is the gross productivity or energy used to do work, P_n is net productivity, and R is respiration or energy to do work. Net production is an increase of stored energy with time, while biomass is total stored energy at any time. If gross production equals respiration ($P_g=R$) no change in energy content results. But when P_g is less than R biomass decreases, and when P_g is greater than R there is an accumulation of biomass.

The gross productivity is dependent on many things, including climatic conditions such as temperature, rainfall, and total solar radiation, and such other features of the abiotic environment as the availability of nutrient materials essential for life, such as nitrogen, phosphorus and sulfur. Following table lists the gross primary production or gross productivity over one year, for several different environments :

Table : Estimated annual gross primary production of a range of ecosystem (**Odum**, 1971; **Clapham, Jr.**, 1973).

Ecosystems	Area (10^6 Km.^{2})	Gross primary productivity (ly./Yr.)
Marine		
1. Open ocean	326.0	100
2. Coastal zones	34·0	200
3. Up welling zones	0·4	600
4. Estuaries and reefs	2·0	2,000
Terrestrial		
1. Deserts and Tundras	40·0	20
2. Grasslands	42·0	250
3. Dry forests	9·4	250
4. Boreal coniferous forests	10·0	300
5. Cultivated land	10·0	300
6. Moist Temperate Forests	4·9	800
7. Mechanized Agriculture	4·0	1,200
8. Wet tropical, subtropical Forests	14·7	2,000

Secondary production : The potential energy resulting from primary production furnishes the energy required by other trophic levels in an ecosystem. Some energy, in the form of food, is consumed by herbivores or omnivores who may be eaten by carnivores, who in turn may be eaten by other carnivores. However, much of this ingested food is not assimilated : herbivores may assimilate only 10 per cent of the ingested food, where as the assimilation coefficiency of carnivores is typically higher. For example, various species of fish absorbed between 86 and 96 per cent of the ingested food, but the efficiency absorption of different classes of food substances varied : about 92–98 per cent of the ingested protein was absorbed, while only 80 per cent of the fat and about 63 –79 per cent of carbohydrates was absorbed by the fishes (**Pandian**, 1967). The unassimilated material leaves the animal's body as waste material to serve as an energy source for other organism (detritus feeders and saprotrophs). Assimilated energy is used by these consumers species for various metabolic processes, such as respiration, excretion, and secretion. The resultant amount of energy stored in the tissues of heterotrophs is termed **net secondary production.** The **gross secondary production** is equivalent to the total plant material ingested by the herbivore, less the materials lost as faeces, That is, it is the food that actually passes through the walls of the gut. Unlike gross primary production, gross secondary production can be measured directly by determining the amount of material defaecated.

Respiration of the population : In previous sections it has been discussed that gross production and net production and the total energy involve respiration or the cost of maintenance of the population. This is expressed in terms of oxygen utilized for vital processes or of carbon dioxide eliminated and so termed **respiration of the population.**

Patterns of flow of energy through the ecosystems : **Thus,** in an ecosystem one can observe the transfer or flow of energy from one tropnic level to other in succession. Primary producers trap radiant energy of sun and transfer that to chemical or potential energy of organic compounds such as carbohydrates, proteins and fats. When a herbivore animal eats a plant (or when bacteria decompose it) and these organic compounds are oxidized, the energy liberated is just equal to the amount of energy used in synthesizing the substances (first law of thermodynamics), but some of the energy is heat and not useful energy (second law of thermodynamics). If this animal in turn is eaten by another one, along with transfer of energy from a herbivore to carnivore a further decrease in useful energy occurs as the second animal (carnivore) oxidizes

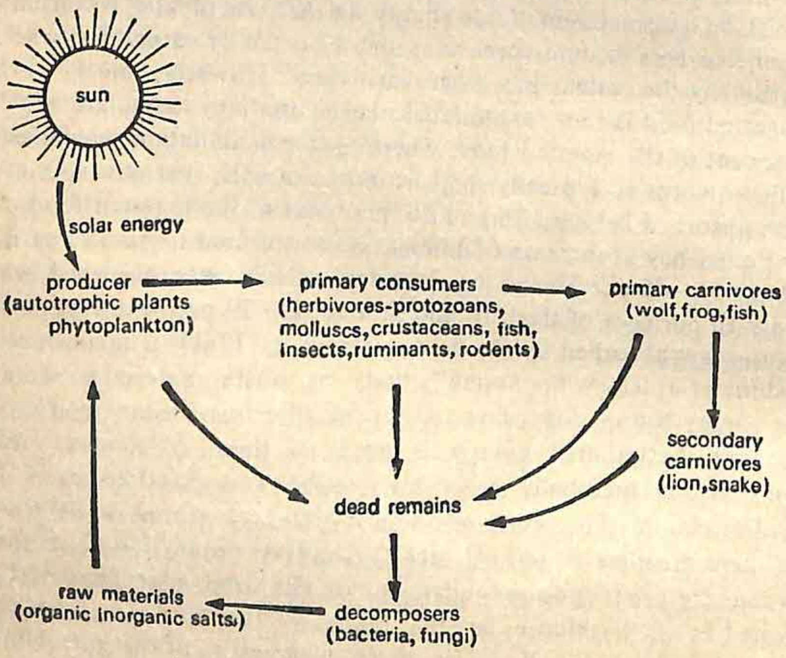


Fig. 7·4. A generalized food chain of the ecosystems.

the organic substances of the first (herbivore or omnivore) to liberate energy to synthesize its own cellular constituents. Such transfer of energy from organism to organism sustains the ecosystem and when energy is transferred from individual to individual in a particular community, as in a pond or a lake or a river, we encounter what are called **food chains**. The number of steps in a food chain is always restricted to four or five, since the energy available decreases with each step. In other words, the energy fixed in organisms such as in aquatic plants in a pond passes through the ecosystem in the form of plant→herbivore→carnivore, where only three steps are encountered in the chain. But very often, the chains are very complicated with several steps being involved. For example, the food-chain of shore ecosystem includes plant→herbivore→carnivore 1→carnivore 2→carnivore n. Basically two types of food chains are recognized—grazing food chain and detritus food chain.

1. **Grazing food chain :** The grazing food chain starts from **green** plants and ends to **carnivores** by passing through herbivores. Thus, gross production of a plant in an ecosystem may meet three fates—it may be oxidized in respiration, it may die and decay and it may be eaten by plant eating animals or herbivores. In herbivores the assimilated food can be stored as carbohydrates, protein or fat, transformed into relatively simple substances or rebuilt by the animal into much more complex organic molecules. The energy to perform these transformations is supplied by respiration. Like autotrophs, the ultimate disposition of energy in herbivores occurs by three routes : respiration, decay of organic matter by bacteria and other decomposer organisms and consumption by carnivores.

The **primary carnivores** or **secondary consumers** eat herbivores or primary consumers of the ecosystems. And likewise, **secondary carnivores** or **tertiary consumers** eat primary carnivores. The total energy assimilated by primary carnivores, or **gross tertiary production**, is derived entirely from the tissues of herbivores, and its disposition into respiration, decay and further consumption by other carnivores is entirely analogous with that of the herbivores. It seems clear that much of the energy flow through grazing food chain can be described in terms of the categories or **trophic levels**, outlined as follows :

$$\left\{\begin{array}{l}\textbf{Autotroph}\\ \text{primary}\\ \text{producers}\end{array}\right\}\rightarrow\left\{\begin{array}{l}\textbf{Herbivore}\\ \text{primary}\\ \text{consumer}\end{array}\right\}\rightarrow\left\{\begin{array}{l}\textbf{Primary carnivore}\\ \text{secondary}\\ \text{consumer}\end{array}\right\}\rightarrow\left\{\begin{array}{l}\textbf{Secondary carnivore}\\ \text{tertiary}\\ \text{consumer}\end{array}\right\}\rightarrow\text{etc.}$$

As a general model for the direction and extent of energy flow within communities, the food chain is very useful. It demonstrates the amount of energy found at any trophic level, the transfer of energy from one trophic level to the next, and the amount of energy lost from the grazing food chain, either through respiration or decay. Further the producer→herbivore→carnivore chain is a **predator chain. Parasitic chains** also exist wherein smaller organisms consume larger ones without outright killing as in the case of the predators.

2. Detritus food chain : The organic wastes, exudates and dead matter derived from the grazing food chain are generally termed **detritus**. The energy contained in this detritus is not lost to the ecosystem as a whole ; rather it serves as the source of energy for a group of organisms (**detritivores**) that are separate from the grazing food chain, and generally termed the **detritus food chain**. The detritus food chain represents an exceedingly important component in the energy flow of an ecosystem. Indeed in some ecosystems, considerably more energy flows through the detritus food chain than through the grazing food chain. In the detritus food chain the energy flow remains as a continuous passage rather than as a stepwise flow between discrete entities. The organisms of the detritus food chain are many and include algae, bacteria. slime molds, actinomycetes, fungi, Protozoa, insects, mites, crustacea, centipedes, molluscs, rotifers, annelid worms, nematodes and some vertebrates. Some species are highly specific in their food requirements and some can eat almost anything. Many Protozoa, for instance, need certain specific organic acids, vitamins, and other nutrients before they can thrive ; on the other hand, the guts of small Collembola (a group of tiny soil insects) have been reported to contain decaying plant material, fungal fragments, spores, fly pupae, other Collembola, parts of decaying earthworms, and cuticle from their own faecal casting (**Hale**, 1967). In contrast to the grazing food chain, in which energy storage is entirely within the tissues of living organisms, energy storage for the detritus food chain may be largely external to the organisms, and is the detritus itself.

Detritus organisms ingest pieces of partially decomposed organic matter, digest them partially, after extracting some of the chemical energy in the food to run their metabolism, excrete the remainder in the form of slightly simpler organic molecules. The wastes from one organism can immediately be utilized by a second which repeats the process. Gradually, the complex organic molecules present in the original wastes or dead tissue are broken down to much simpler compounds, sometimes all the way to carbon dioxide and water. In most instances, however, the organic material is broken down until all the easily biodegradable material has been degraded, and all that is left are some refractory organic substances termed **humic acids**, or simply, humus. In a normal environment the humus is quite stable and will form an essential part of the soil.

Links between grazing and detritus food chains : Just as energy enters the detritus food chain from the grazing food chain as leaf litter, or dead organisms, energy can re-enter the grazing food chain from the detritus food chain if organisms from the latter are consumed by grazers. Considering the diversity of the detritus community, it is not surprising that many of these serve as prey for carnivores in the grazing food chain. A common example is robins eating earthworms. In addition, many insects, among them beetles and flies, spend their larval period in the detritus food chain and their adulthood in the grazing food chain. But through such links through which energy passes from detritus food chain basic into grazing food chain, very little amount of energy is passed in comparison to the amount of energy which flow from grazing food chain to detritus food chain.

ECOLOGICAL PYRAMIDS

In the successive steps of grazing food chain—photosynthetic autotroph, herbivorous heterotroph, carnivores heterotroph, decay bacteria—the number and mass of the organisms in each step is limited by the amount of energy available. Since some energy is lost as heat in each transformation the steps become progressively smaller near the top. This relationship is sometimes called **"ecological pyramids"**. The ecological pyramids represent the trophic structure and

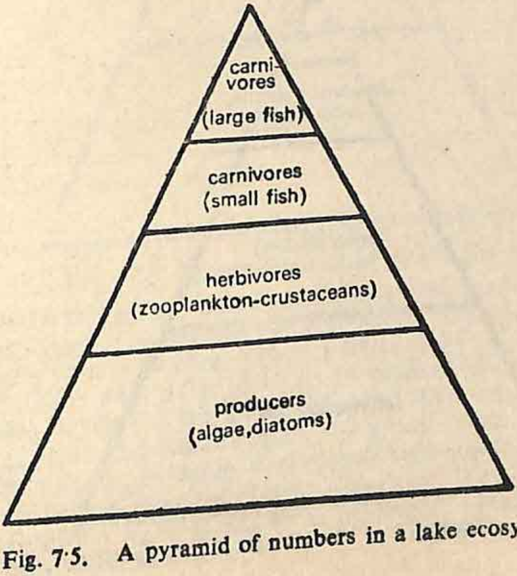


Fig. 7·5. A pyramid of numbers in a lake ecosystem.

also trophic function of the ecosystem. In many ecological pyramid, the producer form the base and the successive trophic levels make up the apex.

Thus, communities of terrestrial ecosystems and shallow water ecosystems contain gradually sloping ecological pyramids because these producers remain large and characterized by an accumulation of organic matter. This trend, however, does not hold for all ecosystems. In such aquatic ecosystems as lakes and open sea, primary production is concentrated in the microscopic algae. These algae have a short life-cycle, multiply rapidly, accumulate little organic matter and are heavily exploited by herbivorous zoo-plankton. At any one point in time the standing crop is low. As a result, the pyramid of biomass for these aquatic ecosystems is inverted : the base is much smaller than the structure it supports.

TYPES OF ECOLOGICAL PYRAMIDS

The ecological pyramids may be of following three kinds :

1. **Pyramids of number :** It depicts the number of individual organisms at different trophic levels of food chain. This pyramid was advanced by **Charles Elton** (1927), who pointed out the great difference in the numbers of the organisms involved in each step of the food chain. The animals at the lower end (base of pyramid) of the chain are the most abundant. Successive links of carnivores decrease rapidly in number until there are very few carnivores at the top. The pyramid of number ignores the biomass of organisms and it also does

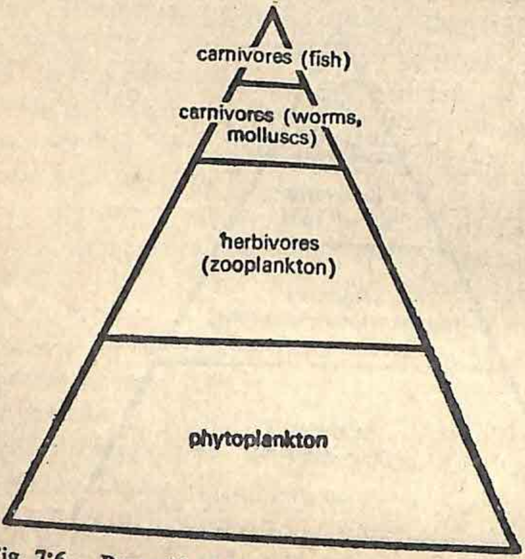


Fig. 7·6. Pyramid of biomass for a marine ecosystem.

not indicate the energy transferred or the use of energy by the groups involved. The lake ecosystem provides a typical example for pyramid of number (Fig. 7·5).

2. **Pyramid of biomass :** The biomass of the members of the food chain present at any one time forms the pyramid of the biomass Pyramid of biomass indicates decrease of biomass in each trophical level from base to apex. For example, the total biomass of the producers ingested by herbivores is more than the total biomass of the herbivores in an ecosystem. Likewise, the total biomass of the primary carnivores (or secondary consumer) will be less than the herbivores and so on.

3. **Pyramid of energy :** When production is considered in terms of energy, the pyramid indicates not only the amount of energy flow at each level, but more important, the actual role the various organisms play in the transfer of energy. The base upon which the pyramid of energy is constructed is the quantity of organisms produced per unit time, or in other words, the rate at which food material passes through the food chain. Some organisms may have a small biomass, but the total energy they assimilate and pass on may be considerably greater than that of organisms with a much larger biomass. Energy pyramids are always sloping because less energy is transferred from each level than was paid into it. In cases such as in open water communities the producers have less bulk than consumers but the energy they store and pass on must be greater than that of the next level. Otherwise the biomass that producers support could not be greater than that of the producers themselves. This high energy flow is maintained by a rapid turn over of individual plankton, rather than an increase of total mass.

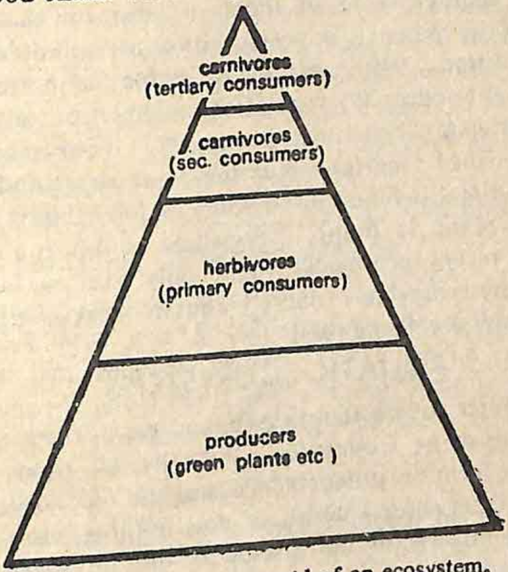


Fig. 7·7. Enregy pyramid of an ecosystem.

CHAPTER 8

AQUATIC ECOSYSTEMS : FRESH-WATER COMMUNITIES

The subject of ecology can be approached through discussions of the principles and concepts of the science as they apply to different levels of organization, the individual, population, community and ecosystem. Another general approach, the **habitat approach**, describes the distinctive features of the major habitats and their subdivisions, how they are organized, the organisms present in each and the ecologic role of these organisms in that region (*i.e.*, the identity of the major producers, consumers and decomposers). According to **Elton** (949) habitat is definable as an area possessing uniformity of physiography, vegetation, climate or any other quality the investigator assumes important. Four major habitats can be distinguished : **marine, estuarine, fresh water** and **terrestrial.** No plant or animal is found in all four major habitats and, indeed, no animal or plant is found everywhere within any one of these. According to recent ecological trend only two major habitats or more specifically ecosystems namely **aquatic ecosystems** and **terrestrial ecosystems**, are recognized.

AQUATIC ECOSYSTEMS

Liquid water covers about three quarters of the earth's surface, either as oceans or as freshwater. Virtually all these waters contain life in one form or other ; hence aquatic ecosystems would be important for their sheer volume, if for nothing else. But aquatic ecosystems are historically the source of life on earth. Even now, tiny single-celled marine plants are the main source of the earths' oxygen supply, because most photosynthetic oxygen is derived from these plants (**Clapham. Jr**., 1973). In addition, aquatic ecosystems are simpler in many ways than terrestrial ecosystems. The reason for this is that the omnipresent environmental factor which sets the tone for all aquatic systems, regardless of their biotic complexity, is water. It is the medium within which all aspects of the ecosystem coexist, both living and non-living ; it is the source of all nutrients for aquatic life, including the gaseous nutrients such as oxygen and carbon dioxide ; it is the medium by which organic and inorganic wastes and sediments are distributed throughout the ecosystem. The amount of light energy reaching the community is determined by the way in which light is absorbed by water ; the heat properties of water determine much of the circulation patterns within the ecosystem and are a major control over the structure of the aquatic community that exists in any one place.

SUBDIVISIONS OF AQUATIC ECOSYSTEMS

Global aquatic systems fall into broad classes definable by salinity, or amount of material dissolved in water—the **fresh-water ecosystem** and **saltwater ecosystems**. The latter may include inland brackish water, as well as marine and estuarine habitats. In fact, estuary represents a transitional zone between a river and the sea and it contains dissolved solid content intermediate between those of fresh and marine waters. Fresh-water ecosystems, the study of which is known as **limnology**, are conveniently divided into two groups—**lentic, standing** or **still water habitats** and **lotic** or **running water habitats**. Both can be considered on an environmental gradient. The lotic follows a gradient from springs to mountain brooks to streams to rivers. The lentic involves a gradient from lakes to ponds to bogs, swamps and marshes.

FRESH WATER ECOSYSTEMS : PHYSICO-CHEMICAL NATURE OF FRESHWATER

The fresh water of both kinds—lentic and lotic, has low percentage of dissolved salts and is subjected to the influence of an array of physical and chemical factors. The rise and fall of these factors very frequently affect the fauna, altering their number and diversity. Some of the important factors of fresh water environment are following :

1. PRESSURE, DENSITY AND BUOYANCY

The pressure imposed on a lake-dwelling organism is the weight of the column of water above it plus the weight of the atmosphere. In all fresh water environments maximum pressure is much less than in the ocean, and organisms appear to adjust to them readily. The absence of animal life from deep water is ordinarily a consequence of low oxygen supply, or low temperature, rather than pressure.

The density of water varies inversely with temperature and directly with the concentration of dissolved substances. Water is most dense at approximately 4°C and becomes progressively less dense as it cooled below +4°C. Ice also expands markedly the colder it gets It is because the coldest water is at the surface in winter that ice forms there, rather than at the bottom of a lake. In summer, the coldest waters of deep lakes are at the bottom. Dissolved salts increase the density of water ; the density of most inland water-bodies is much less than that of the ocean. However, when great evaporation occurs in a lake having no outlet, the lake may come to contain a higher precentage of salts(*i.e.*, hypersalinity) than the ocean. The few species capable of living in these very salty lakes (*e.g.*, Great Basin of USA) include some algae and Protozoa, the brine shrimp *Artemia gracilis* and the immature stages of two brine flies, *Ephydra gracilis* and *E. hians*.

According to the **law of Archimedes**, the buoyancy of an object is equal to the weight of the water it displaces. Buoyancy varies with the density of water, and is influenced by the factors that affect density. Viscosity, the measure of the internal friction of water, varies inversely with temperature and also influence buoyancy. Most aquatic organisms keep stations by **swimming movements** or **have** special adaptations to decrease the specific gravity of the body and take advantage of any turbulance in the water. For this purpose fresh water aquatic organisms have some swimming adaptations, clinging organs (in case of animals of lotic habitat) or following adaptations—absorption of large amounts of water to form jelly-like tissues ; storage of gas or air bubbles within the body ; formation of light-weight fat deposits within the body or oil droplets within the cell ; increase of surface area in proportion to body mass, which increase frictional resistance (**Davis**, 1955). When an organism so equipped dies, the special mechanisms quickly cease to function, and it sinks to the bottom.

2. TEMPERATURE

The unique thermal properties of water are best demonstrated by fresh-water environments. Diurnal and seasonal variations of temperatures are very much evident in these environments than in marine environments. A diurnal variation range of 4·8—5·0°C has been recorded by **Sreenivasan** (1964) in a tropical lake, with an average depth of 3·0 meters. In shallow water habitats, difference between day and night temperatures remain more conspicuous. For example, in a polluted moat with an average depth of 1·5 meters, the lowest night time temperature was 26·6°C, the highest day time temperature was 32·0°C with a variation of 5·4°C (**Sreenivasan**, 1964). However, the Kodaikanal lake in South India showed a diurnal variation of only 2·8°C (**Sreenivasan**, 1964). Flowing lotic waters of streams and rivers lack such wide fluctuations in temperature.

Further, the lentic water of lakes and ponds undergo thermal stratification phenomenon according to the seasons. Thermal stratification have been reported most frequently in the lakes of tropical countries like Java, Sumatra, etc. In fact, according to their temperature relations, lakes have been classified into three types : (1) **Tropical lakes** in which surface temperatures are always maintained above 4°C ; (2) **Temperate lakes** in which surface temperature vary above and below 4°C and (3) **Polar lakes** in which surface tem**peratures never** go above 4°C. The seasonaly regulated thermal stratification of lentic habitats has a significant influence on their inhabitant biotic communities. Decreasing temperatures often cause a fall in metabolism, resulting in a lower rate of food consumption. The extremes of lower and higher temperature have lethal effects on the aquatic organisms. So fluctuations in temperature of aquatic media regulate the breeding periods, initiate hibernation, gonadial activitation and a number of other biological phenomena such as thermally oriented migration, etc., of fresh water biota. On the basis of their ability to tolerate thermal variations, most fresh water organisms are **stenothermic** with a narrow range temperature tolerance, but some are **euthermic** with a wide range of temperature tolerance. For example, the stenothermic oligochaets includes **stenominimothermal forms** (narrow range of temperature, *e.g.*, *Aeolosoma*, *Megascolex mauritii)*, **stenomaximothermal** (*e.g.*, *Dero limosa*) or **stene-optimothermal forms** (*e.g.*, *Branchiodrilus semperi and B. menoni*) **(Sitaramiah,** 1966).

3. LIGHT

Light influences fresh water ecosystems greatly. The freshwaters often have a lot of suspended material. While affording protection to the light sensitive species, these substances more often obstruct the light that normally reaches the water. The degree of such obstruction of light influence the productivity of the fresh water ecosystems. A shallow lake receives light to its very bottom resulting in an abundant growth of vegetation both phytoplankton and rooted vescular plants, These plants in living or dead states form nice food for consumers of grazing food chain or organisms of detritus food chain, respectively. The running water contain little plant or animal plankton not due to the lack of sunlight but because of the action of the currents in washing it away. Further, light controls the orientation and changes in position of attached species and their nature of growth and it also caused into diurnal migrations of planktonic species of fresh water.

4. OXYGEN

Chemically pure water is biologically uninhabitable and all fresh water contains an array of chemical substances. The oxygen, which is a most essential chemical component of life processes, remain dissolved in fresh waters. The aquatic environments which remain in close proximity with atmosphere contain an abundance of oxygen, that reaches the water either by direct diffusion or by movements of water like wave action or water circulation. Lotic (moving) water of streams and rivers often have a high percentage of oxygen. Aquatic plants supply water with oxygen that is formed as a product of photosynthesis. Rooted vegetation of shallow water zones and floating phytoplankton of open waters also produce oxygen. The amount of photosynthetically produced oxygen remain high at warm temperatures and greater light intensities.

The oxygen level in a tropical pond exhibits diurnal variation—it remains at peak between 14·00 and 17·00 hours of day (**Sreenivasan**, 1964). Oxygen contents of a fresh water body are **depleted** in numerous ways. Primarily oxygen is utilised in the respiration of organisns and decomposition of dead orgnisms in the aquatic environment. While photosynthesis remains restricted to the surface layers of water containing phytoplankton and exposed regions of rooted vascular plants, respiration and decomposition occur at all levels. In stagnant pools with a lot of decaying vegetation oxygen content often reaches a stage of complete depletion. The reduction in dissolved oxygen is magnified by the release of many gases as end products of decomposition or by the mixing up of waters of low oxygen content reaching the habitat as an inflow. Aquatic animals with very few exceptions, *i.e.*, those that breathe air, utilize the oxygen dissolved in water. Certain fresh water inhabitants such as many anaerobic bacteria and insect larvae of chironomids perform anaerobiosis and requires no oxygen.

5. CARBON DIOXIDE

Aquatic vegetation and phytoplankton require carbon dioxide for photosynthetic activity. The carbon dioxide of fresh water environments is produced as the end product of respiration and of decomposition. Carbon dioxide also diffuses directly from the atmosphere and is readily dissolved in water to result in carbonic acid (H_2CO_3) which affects the pH of water. It is also present in the fresh water as carbonates and bicarbonate of calcium, magnesium and other minerals. The growing plants and lime depositing bacteria and other animals may cause a depletion in carbon dioxide resources. Photosynthesis is the major cause for its drain. The high saturation levels of O_2 and CO_2 have been found to have toxic effects on aquatic biota.

6. OTHER GASES

Streams and lakes contaminated by sewage and stagnant pools with decaying vegetation show an abundance of the gas hydrogen sulphide which is a decomposition product. This gas is highly toxic to living organisms and results into complete denudation of bottom fauna. Methane and carbon monoxide are other toxic gases which are the products of decomposition. Nitrogen, hydrogen, sulphur dioxide and ammonia are some of the other gases which are found dissolved in fresh waters.

7. DISSOLVED SALTS AND SALINITY

Fresh water being efficient solvent contains many solutes in solution, but even then its salt contents remain under $\frac{1}{5}$ ‰ than marine water which contains about thirty-five parts per thousand (‰) dissolved salts (see **Clapham, Jr.**, 1973). Different dissolved salts reach the water by erosion, inflow and decay of aquatic forms. Dissolved substances have peculiar significance for floating aquatic vegetation and phytoplankton, since these organisms do not depend on the substratum for the supply of nutrients. Compounds of nitrogen, phosphorus and silicon are most important substances found dissolved in fresh water. Nitrate, nitrites and ammonium salts are essential for the food of aquatic vegetation such as algae and water weeds. Nitrate always remain available due to nitrogen cycle occurring between nitrogen fixing bacteria and nitrogen consuming plants. Ammonium salts in excess have a lethal effect on the fauna. Dissolved silicates of freshwater are readily utilized by diatoms and sponges in constructing their body structures such as shell in case of diatoms and spicules in case of sponges.

All fresh water environmants also contain small amounts of phosphorus which more often acts as a limiting factor. Utilization of phosphorus by plankton during the periods of abundance may result in a total elimination of other plants that require the element (phosphorus). Many other elements like calcium magnesium. manganese, iron, sodium, potassium, sulphur, and zinc are found dissolved in water and influence the fauna variously. Iron being a growth promoting element for plants exists as the compound of oxygen (ferrous oxide) or sulphur (ferrous sulphide) in different freshwater bodies. Its influence is often modified by the pH of water. Calcium is an essential element for plants. The abundance and scarcity of carbonate of calcium determine the faunal composition. Deposition of calcium carbonate in water called **marl** is produced by the activity of plants. External coverings of arthropods and the shell of molluscs and tubes of some worms need calcium carbonate, snails are found to develop a heavy shell if the waters in which they lived contained excess of calcium. Bryozoans, sponges, and cladocerans prefer an increased calcium content.

Due to low salinity of fresh water animals face the problem of **osmoregulation**. Because the salt concentration of body fluids of animals remain higher than the fresh water hence the water continuously tend to enter the body which should be readily removed. Most aquatic animals (*e. g.*, Protozoa and fishes) have the means to excrete extra amount of water of body by osmoregulation. For this purpose Protozoa employ contractile vacuoles and other multicellular invertebrates and chordates use excretory organs, such as nephridia, kidney, etc.

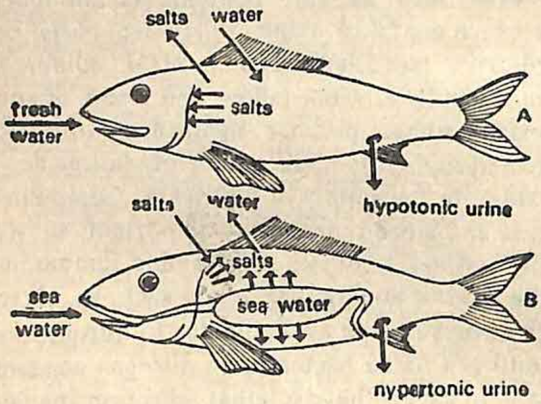


Fig. 8·1. Osmoregulation in (A) fresh water fish and (B) marine fish.

8. PH OR HYDROGEN ION CONCENTRATION

In freshwater environments pH is a determining factor for the biota by becoming a limiting factor. The pH value of different freshwater bodies may fluctuate seasonally and annually. The pH of surface waters and deeper waters exhibit marked differences. **Sreenivasan** (1968) has reported a marked pH variation of 2·2 units between surface waters and deeper waters in the Sandynulla reservoir in the Nilgiris (India). Though pH range species specific, yet lower aquatic forms in general showed little reaction to alterations in pH, while higher aquatic organisms (*e.g.*, fishes) responded quickly to little pH variations.

LENTIC ECOSYSTEMS

Lentic ecosystems include all standing water (freshwater) habitats such as lakes, ponds marshes, swamps, bogs, meadows, etc. Some of the important lentic ecosystems or wetlands have been tabulated in following table :

Table : Classification of wetland or lentic ecosystems (excluding lakes and ponds) (**Smith**, 1974).

A. Inland freshwater areas	
1. Seasonally flooded	Soil covered with water or waterlogged during variable periods but well-drained during much of the growing season. In upland depressions and bottomlands. Bottomland hardwoods to herbaceous growth.
2. Fresh water meadows	Without standing water during growing season ; water logged to within few inches of surface. Grasses, rushes, sedges broad-leaf plants.
3. Shallow freshwater marshes	Soil waterlogged during growing season ; often covered with 6 inches or more of water. Grasses, bulrushes, spike rushes, cattails, arrowhead, smartweed, pickerelweed. A major water-fowl-production area.
4. Deep freshwater marshes	Soil covered with 6 inches to 3 feet of water. Cattails, reeds, bulrushes, spikes rushes, wild rice. Principal duck-breeding area.
5. Open fresewater marshes	Water less than 10 feet deep. Bordered by emergent vegetation : pondweed, naiads, wild celery, water lily. Brooding, feeding, nesting areas of ducks.
6. Shrub swamps	Soil waterlogged; often covered with 6 inches or more of water. Alder, willow, buttonbush, dogwoods. Ducks nesting and feeding to limited extent.
7. Wooded swamps	Soilwaterlogged; often covered with 1 foot of water. Along sluggish streams, flat uplands, shallow lake basins. North of USA : tamarack, arborvitae, spruce, red maple, silver maple, south of USA : water oak, overcup oak, tupelo, swamp black gum cypress.
8. Bogs	Soil waterlogged; spongy covering of mosses. Heath shrubs, sphagnum, sedges.
B. Coastal freshwater areas	
9. Shallow freshwater marsh	Soil waterlogged during growing season ; at high tides as much as 6 inches of water on landward side, deep marshes along tidal rivers, sounds, deltas. Grasses and sedges. Important water-fowl areas.
10. Deep freshwater marshes	At high tide covered with 6 inches to 6 feet of water. Along tidal rivers and bays. Cattails, wild rice, giant cutgrass.
11. Open freshwater	Shallow portions of open water along fresh tidal rivers and sounds. vegetation scarce or absent. Important water-fowl areas.

I. LAKES AND PONDS

Lakes are inland depressions containing standing water. They may vary in size from small ponds of less than acre tc large seas covering thousands of square miles. They may range in depth from a few feet to over 5,000 feet **Ponds**, however, are considered as small bodies of standing water so shallow that rooted plants can grow over most of the bottom. Most ponds and lakes have outlet streams and both are more or less temporary features on the landscape because filling no matter how slow, is inevitable.

The aquatic habitats of lake and pond remain vertically stratified in relation to light intensity, wave length absorption, hydrostatic pressure, temperature, etc. In a lake, for example, there are three well recognized horizontal strata namely : **(i)** Shallow water near the shore forms the **littoral zone**. It contains upper warm and oxygen rich circulating water layer which is called **epilimniou**. The littoral zone includes rooted vegetation. **(ii) Sublittoral zone**-extends from rooted vegetation to the non-circulating cold water with poor oxygen zone, *i.e.*, **hypolimnion**. **(iii) Limnetic zone** is the open water zone away from the shore. It is the zone upto the depth of effective light penetration where rate of photosynthesis is equal to the rate of respiration. **(iv) Profundal zone** is the deep-water area beneath limnetic zone and beyond the depth of effective light penetration. **(v) Abyssal zone** is found only in deep lakes, since it begins at about 2,000 meters from the surface. Ponds have little vertical stratification. In them littoral zone is larger than the limnetic zone and profundal zone. In a small pond the limnetic and

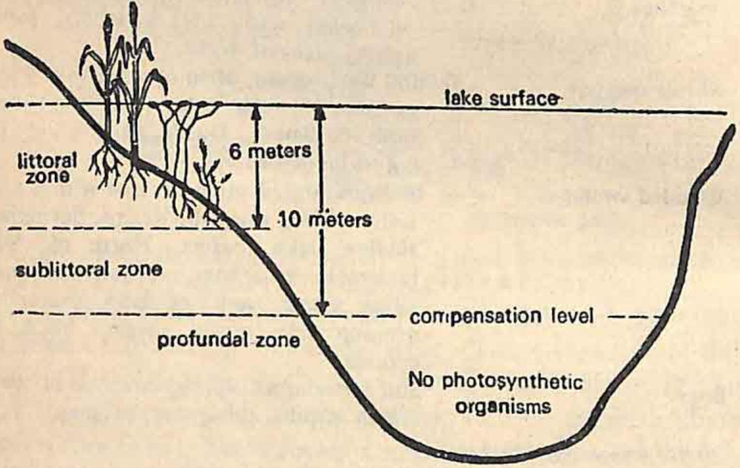


Fig. 8·2. Different zones of a deep freshwater lake.

profundal zone are not found. Lakes thus differ ponds in having relatively larger limnetic zone and profundal zone than littoral zone.

Further, lentic water of a lake or pond is also classified on the basis of the depth of light penetration enabling photosynthesis into **trophogenic zone** (includes littoral plus sublittoral zones), and a **tropholytic zone** (upper part of profundal zone). The former is often distinguished by abundant plant growth and dependent fauna, while the latter denotes a general absence of vegetation and harbours mostly saprobes. In between the two zones is the **compensation level** which forms a boundary between two zones. It exhibits perfect equilibrium between respiration and photosynthesis.

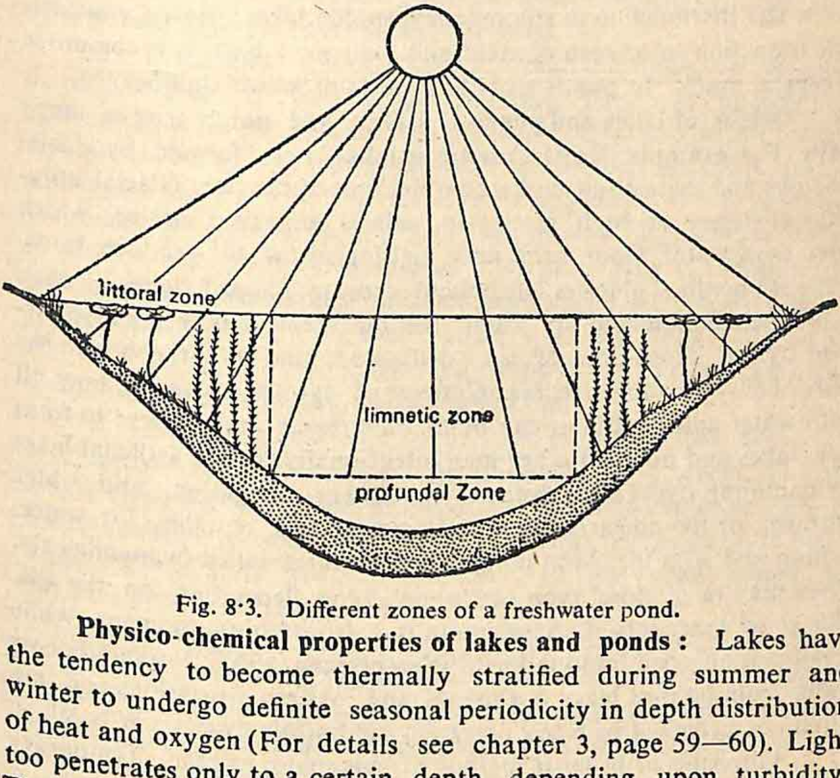


Fig. 8·3. Different zones of a freshwater pond.

Physico-chemical properties of lakes and ponds : Lakes have the tendency to become thermally stratified during summer and winter to undergo definite seasonal periodicity in depth distribution of heat and oxygen (For details see chapter 3, page 59—60). Light too penetrates only to a certain depth, depending upon turbidity. These gradations of oxygen, light and temperature profoundly influence life in the lake, its distribution and adaptation.

Different classifications of lakes on the basis of physical factors productivity, etc., exist. Based on temperature **Hutchinson** (1957) classifies lakes into **dimictic, monomictic** and **polymictic** lakes. The dimictic lakes exhibit two overturns every year, while monomictic lakes present only a single overturn per year. The monomictic lakes may be **cold monomictic** and **warm monomictic**, the former being characterized by a circulation only during summer, while the latter has a complete circulation in winter as well. Polymictic lakes present circulations throughout the year. Based on the humic acid contents the lakes of world have been classified into **clear water lakes** and **brown water lakes**, brown water contains high humus content. Clear water lakes may be divided into two types—the **oligotrophic type,** whose water is poor in nutritive plant material and shows nearly equal distribution of oxygen during summer and winter months and whose mud bottom contains little organic material ; and the **eutrophic type,** which is rich in nutrients. At greater depth below the thermocline in summer euthrophic lakes show a considerable reduction in oxygen content and their mud bottom is composed of typical muck. In ponds strasification is of minor significance.

Origin of lakes and ponds : Lakes and ponds arise in many ways. For example, North American lakes were formed by glacial erosions and deposition and a combination of the two. Glacial abrasions of slopes in high mountain valleys engraved basins, which filled with water from rain and melting snow to produce tarns. Retreating valley glaciers left behind crescent-shaped ridges of rock debris, which dammed up water behind them. Lakes are also formed by the deposition of silt, driftwood, and other debris in the beds of slow-flowing streams. Craters of extinct volcanos may fill with water and landslides can block off streams and valleys to form new lakes and ponds. Futher man intentionally creates artificial lakes by damming rivers and streams for power, irrigation, and water storage, or by constructing small ponds and marshes for water, fishing and wild life. Man made lakes are often called **impoundments**. They may be a 'close' type or 'open' type depending on the discharge of water into it. Sandynulla is a closed impoundment, while Pykara is an open impoundment (**Sreenivasan**, 1957). Impoundments differ from natural lakes in thermal and oxygen variations and are often characterised by a low percentage of bottom dwellers or benthos.

Ponds occur in most regions of adequate rainfall. Temporary ponds, which are often shallow and quick drying contain a characteristic lentic environment. Permanent ponds contain water throughout the year, while flood-plain ponds are formed when a stream shifts its position, leaving the formed bed isolated as a body of standing water.

BIOTIC COMMUNITIES OF LAKES AND PONDS

Different organisms of the lentic environment can be ecologically classified based on whether they are dependent on the substratum or free from it. Organisms depending on the substratum are called **pedonic forms** and those that are free from it are the **limnetic forms**. Further, the aquatic organisms may also be classified into following groups depending upon their sizes and habits :

1. **Neuston :** These are unattached organisms that live at the air-water interface. They may include floating plants such as duckweed, as well as many types of animals. Animals that spend their lives on top of the air-water interface, such as water striders, are termed **epineuston**, while others, including insects such as diving beetles and back swimmers, which spend most of their time on the underside of the air-water interface and obtain much of their food from within water, are termed **hyponeuston**.

2. **Plankton :** These are forms which are found in all aquatic ecosystems except for fast-moving rivers. They are small plants and animals whose powers of self-locomotion are so limited that they cannot overcome currents. Thus their distribution is controlled largely by the currents in their ecosystems. Most planktons (phytoplanktons and zooplanktons) can move a bit, however, either, to control their vertical distribution or to seize prey. Certain animal planktons or zooplanktons are exceedingly active and move relatively great distances considering their small size, but they are so small that their range is still controlled largely by currents and such planktons are also known as **nektoplankton**.

3. **Nekton :** Nektonic animals are swimmers and are found in all aquatic systems-except for the fastest-moving rivers. In order to overcome currents, these animals are relatively large and powerful ; they range in size from the swimming insects of quiet water, which may be only about 2 mm long, to the largest animal that has ever lived on earth, the blue whale.

4. **Benthos :** The benthos includes the organisms living at the bottom of the water mass. They occur virtually in all aquatic ecosystems. The benthos organisms living above the sediment-water interface are termed **benthic epifauna** and those living in the sediment itself are termed **infauna.**

Biota of littoral zone : Lentic aquatic life is most prolific in the littoral zone. The littoral zone of a lake remains rich in pedonic flora especially upto the depth to which effective light penetration is possible facilitating the growth of rooted vegetation. At the shore proper are the **emergent vegetation** which remain firmly rooted in the shore substratum but their tops with thin chlorophyll bearing regions are exposed. Interspersed with these plants are the cattails (*Typha*), bulrushes (*Scirpus*), arrowheads (*Sagitaria*) and pickerelweeds. Out slightly deeper are the rooted plants with floating leaves such as the water lilies—*Nymphaea*, *Potamageton*, etc. Still deeper in the littoral zone of lake are the fragile thin-stemmed water weeds, rooted but totally submerged. Such a submerged vegetation inclndes plants like *Elodea*, *Vallisneria*, *Myriophyllum*, etc.

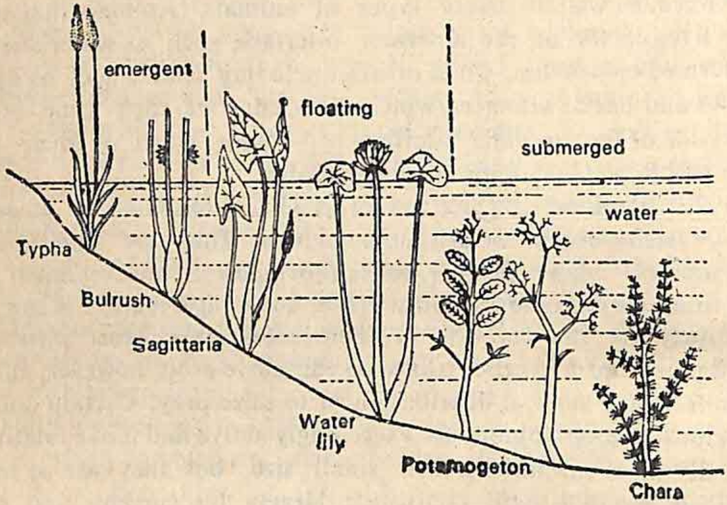


Fig. 8·4. Flora of the lentic habitat.

The phytoplankton of littoral zone of lake is chiefly composed of diatoms *(e.g., Navicula, Cyclotella)*, blue green algae *(e.g., Microcystis, Oscillatoria)*, green algae (*e.g.*, *Cosmarium*, *Staurastrum*) and holophytic flagellates. **Sreenivasan** (1970) has observed the abundance of marine dinophycean flagellate *Ceratium hirudinella* in some impoundment of India.

The littoral zone also contains great concentration of animals, which remain distributed in recognizable communities. In or on the bottom are various dragonfly nymphs, crayfish, isopods, worms, snails and clams. Other animals live in or on plants and other objects projecting up from the bottom. These include protozoans like *Vorticella*, *Stentor* ; larvae of *Dytiscus*, *Laccotrophes*, leech-like *Glossophonia*, climbing dragonfly, damsel fly nymphs, rotifers (*Brachionus*), flat worms, Bryozoa, hydra, snails (*Lymnaea*) and other. With the exception of a few rotifers like *Keratella*, *Brachionus*, *Diurella*, and *Trichocerca* and crustaceans like *Cyclops*, *Daphnia* and *Moina*, most freshwater animals of lentic habitat depend in one way or other on the aquatic vegetation. Larvae of *Chironomus* are found to inhabit the interior of rotting vegetation. Planarians are found underneath the leaves of floating plants. The zooplankton of littoral zone consists of water fleas such as *Daphnia*, rotifers and ostracods The free swimming fauna (Nekton) includes *Paramecium*, *Euglena*, *Ranatra*, *Corixa*, *Dytiscus*, larvae of *Culex* and of *Chaoborus*, *Gerris*, *Gyrinus*, etc. Among the vertebrates are frogs, salamanders, snakes and turtles are the nektons of littoral zone. Floating members of the community (neuston) are whirliging beetles, water spiders and numerous Protozoa. Many pond fishes such as sun-fish, top minnows, bass, pike and gar spend much of their time in the littoral zone.

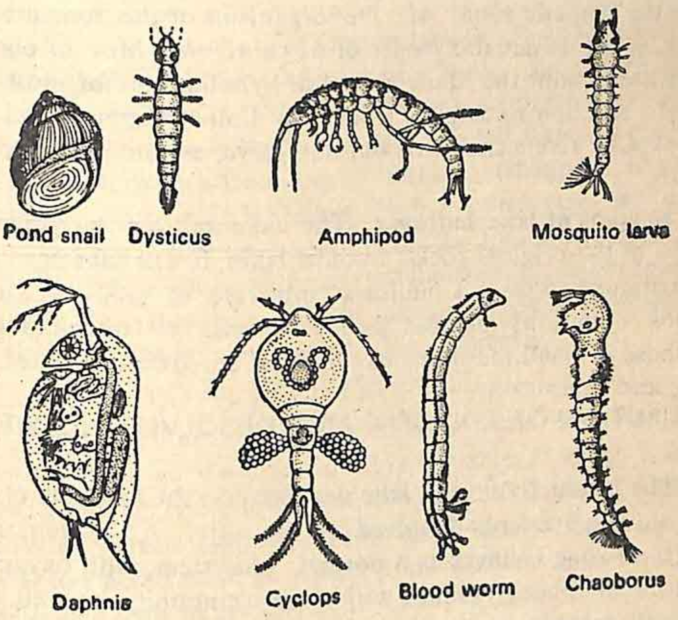


Fig. 8·5. Fauna of littoral zone of lentic habitat.

Biota of limnetic zone : Limnetic zone is the region of rapid variation, with the water level, temperature and oxygen content varying from time to time. In certain Himalayan lakes which have a glacial origin, change in water level is a conspicuous phenomenon, the onset of summer bringing forth a rapid and sudden rise in water level. Various protozoans which are capable of encystment during adverse ecological conditions, tardigrades like *Macrobiotus*, rotifers like *Rotaria*, *Philodina*, copepods, snails and frogs occupy the limnetic zone. Sedentary and slow moving forms are excluded from this zone because of predators and lacking of permanent substratum for attachment. Many microscopic plants (*Volvox*, *Euglena*) and fishes also occupy this zone. The limnetic zone has autotrophs in abundance.

Biota of profundal zone : The deep (profundal) life consists of bacteria, fungi, clams, blood worms (larvae of midges), annelids and other small animals capable of surviving in a region of little light and low oxygen. In the profundal zone, autotrophs cannot produce food, and the main source of energy is detritus that rains out of the limnetic zone. All the organisms of this zone are heterotrophs, either as detritus feeder or as carnivores. Most of our largest lake fishes inhabit the dark waters of hypolimnion for most of their lives. In addition to detritus from the limnetic zone, food washed into lakes by rivers can settle out and serve as food for profoundal animals.

Benthos of lake bottom : The lake bottom in young lakes may be of the original rock ; in older lakes, it will have been covered with sediment to form a uniform substrate of mud or sand. The benthos community includes several species of insect larvae, including those of small mosquito like midges, burrowing mayflies, clams, snails, and tubeworms.

DISTRIBUTION OF OXYGEN AND DISSOLVED NUTRIENTS IN LAKES

The productivity of a lake depends on the amounts of oxygen and available nutrients dissolved in the water. As a general rule, the littoral zone behaves as a normal ecosystem, with oxygen being produced by photosynthesis within the community, as well as being constantly mixed into the water at the surface. Productivity within the littoral is directly controlled by the nutrients cycling within the littoral zone ecosystem and biogeochemical cycles apparently operate as do in terrestrial ecosystems, with sediments serving as a storage place for inorganic nutrients such as phosphate, and some rooted plants being able to draw nutrients out of the sediments through their roots (**McRoy** and **Barsdate**, 1970). But in the pelagic zone (limnetic and profundal zones), the distribution of oxygen and nutrients is exceedingly uneven, and this has a profound effect on the behavior of the lake as a whole, especially in those whose pelagic zone is much larger than the littoral.

The epilimnion of a lake is typically well oxygenated, both because of the production of photosynthetic oxygen in the epilimnion and because of the oxygen uptake at the surface. The amount of nutrients dissolved in the water is highly variable, mainly because most of the nutrients in the epilimnion have been incorporated into living tissue. Thus, production of epilimnion is controlled by amount of available nutrients, which, in turn is controlled primarily by the rate of cycling within the epilimnion, the rate of loss to the hypolimnion of nutrient-rich detritus, and the rate of return of soluble nutrients from the hypolimnion during overturn. The fact that only heterotrophic metabolism proceeds in the hypolimnion means that the level of production is determined by the amount of detritus raining into it. As the decomposition of detritus release soluble nutrients, therefore, there is an inverse relationship between oxygen concentration and concentration of vital nutrients. It is paradoxical that the greater the productivity of a lake the lower the oxygen concentration in its hypolimnion. For example, oligotrophic lake which is virtually sterile biologically has low production but its water remain well saturated with oxygen from top to bottom (**orthograde oxygen curve**). Likewise, a eutrophic lake has high productivity, but there is substantial oxygen depletion from top of the hypolimnion to the bottom, with depletion most extreme in the bottom layers (**clinograde oxygen curve**). However, in most lakes, oxygen is thoroughly mixed and is essentially at saturation during overturn.

LOTIC ECOSYSTEMS

Moving-water or lotic ecosystems includes rivers, streams, and related environments. They are remarkably variable, ranging in size from Ganga, Yamuna, Hindon, Gomti, etc., to the trickle of a small spring. They vary from raging torrents and water-falls to rivers whose flow is so smooth as to be almost unnoticeable. A given river varies considerably over its length, as it changes from a mountain brook to a large river. This is most noticeable in the abiotic factors of the environment, but all features of the ecosystem vary in response.

CHARACTERISTIC OF LOTIC ENVIRONMENT

Moving waters differ in three major aspects from lakes and ponds : current is a controlling and limiting factor; land-water interchange is great because of the small size and depth of moving water systems as compared with lakes; oxygen is almost always in abundant supply except when there is pollution. Temperature extremes tend to be greater than in standing water. Besides these, the most distinctive features of moving water ecosystems are those related to their motion, *i.e.*, the **rate of flow** and the **stream velocity**. The rate of flow or discharge refers to the volume of water passing a given observation point during a specific unit of time ; it is measured in units such as m.^{3}/sec., ft.^{3}/sec., or acre-feet/sec., (one acre-foot is equivalent to a volume of water 1 acre in area by 1 foot deep). It tends to increase steadily going down stream, as tributaries join with the main river. The **velocity of flow** is the speed at which the water moves, and is measured in m./sec., ft./sec., or mi./hr. Velocity is variable, but it also tends to increase downstream with increasing discharge. A factor that may be even more important to the biotic community is the **turbulence**, or the irregularity of the motion of the water particles. Perfectly even flow, in which water particles move parallel to one another, is called **laminar flow**. It is contrasted with **turbulent flow**, in which the movement of water particles is highly irregular. In highly turbulent water the erosive power is great, the sheer forces at the water-sediment interface at the bottom of the river are powerful, and the amount of oxygen incorporated into the water is very high. In streams with laminar flow the erosive power is lower, the shear forces at the bottom of the stream are lower, and relatively less oxygen is incorporated into the water than turbulent waters.

The moving-water ecosystems can be divided into following two ecosystems depending up on the velocity and rate of flow of water body :

1. Rapidly flowing water and 2. Slowly flowing water.

I. RAPIDLY FLOWING WATER

Rapidly flowing water (of fast moving torrential streams, etc.) can be defined as the portion of the stream in which the flow is both rapid and turbulent. Everything that is not attached or weighted is swept away by the current; this includes organisms and sediment particles alike. The substrate tends to be rock or gravel, and the fragments are rounded and smoothed by the water. The habitat itself is an extremely diverse one. Physical parameters such as sheer force and rate of water movement tend to be quite different on top of a rock fragment, between rock fragments, or beneath rock fragments, and different species can exploit these differences in microhabitat. Aquatic plants, in addition, provide microhabitat for some torrential animals. The rarely occurringphytoplankton of **rapid** or **riffle zone** of stream includes diatoms, blue-green and green algae (*e.g., Cladophora, Ulothrix*) and water moss (*e.g., Fontinalis*).

1. Plant inhabiting torrential forms : Some animals of rapidly flowing water streams live among the mosses and flowering plants like *Eriocaulon miserum*, *Hydrolyum lichenoides*, and *Duroea wallichii*. Animals inhabiting these plants have a torpedo-like body which enables them to offer minimum resistance to the current. Some animals such as funnel mouthed tadpoles of *Megalophrys* and tipulid larvae live entangled in the roots of these plants. They possess devices for fixation and have hydrostatic organs.

Some animals such as *Cephalopteryx, Helodes, Phalacrocera, Gammarus*, etc. live among leaves and stems of aquatic plants. All these animals possess hook-like structures on their body helping them in anchoring on leaves and stems. The larvae of simulids and chironomids, however, live on the exposed surfaces of plants.

2. Rock inhabitant forms : The animals that live on the tops of exposed rocks have an efficient mechanism for staying in one place, otherwise, they will be swept away. The organisms in this microhabitat are universally flattened. Some, like the fresh water limpet, *Ferrissia*, are virtually flat, offering little resistance to the current, and holding themselves in place with a very large powerful foot that extends over almost the entire area of the shell. Others, such as water penny, the larvae of the riffie beetle, and *Baetis* larvae, are not only almost flat, but each of their legs possesses hooked claws that enable them to hold onto the substrate more firmly. Larvae of *Simulium* and chironomids cling to rock top by grapling hooks at the posterior end of the body. Caddishfly worms contain both of these structures (claws on legs and hooks at posterior end of body). The mayfly nymphs *Iron* and *Psephenus* attach themselves to the rocks by means of functional pads. Some animals, including fresh-water sponges, actually cement themselves to the surface of the rocks. Others, such as caddish flies, build "houses" out of sediment or wood fragements, which are then cemented firmly to the rocks. Exposed surfaces of rocks also contains few sessile algae and few plants. A significant amount of organic detritus is washed into rapid-water ecosystems from up stream and adjacent terrestrial areas, however. This is the source of the most of energy in fast water ecosystems, and is much more important as an energy source than primary production within the stream itself. In consequence, the majority of primary consumers of such a microhabitat are detritus-eaters.

3. Inhabitant forms of spaces between rocks : Numerous different kinds of animals live in the spaces between the rocks. Many of them, such as mayfly and stonefly naiads, are flattened and have certain behavioral adaptations to hold them in place. These include **thigmotaxis**, by which they cling instinctively to any hard surface such as rock or another insect larva. **Rheotaxis**, by which the animals orient themselves to face into current and move upstream is another adaptation of this sort. In many of these naiads, the combination of the organisms shape and behaviour is such that the current presses the insect tightly against the rock, increasing the friction between the animal and its substrate. Other insect larvae, such as the hellgramite, are large and covered with spines. Their size make it somewhat harder for the current to sweep them away, while the spines help in holding the larvae in places between stones.

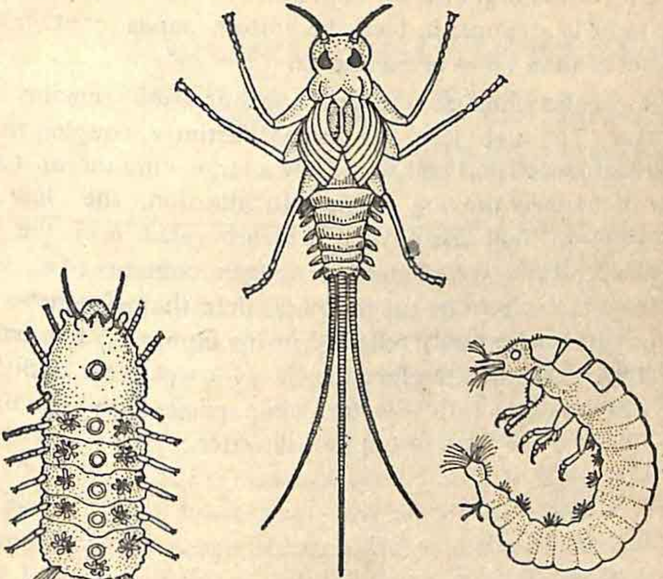
4. **Inhabitants occurring beneath rocks :** Many species such as flatworms, annelid worms, other insect larvae, clams and some species of snails, live beneath the rocks. The current is weaker here, and animals are less likely to be carried away. They lack any special adaptation.

Finally, if the current is sufficiently slow, certain swimming organisms such as fish, will be present. The fish of fast-water ecosystems tend to be stenothermal cold-water fish, such as trout. The fishes of fast-water ecosystems have small body size and streamlined body. Trout and masheer are capable of moving against the current or waterfall by muscular effort. Majority of torrential fishes, however, live on or among rocks and boulders, over which water flows very swiftly. Small loaches (*Noemacheilus*) or loach-like fishes (*Ambyceps olyra*) are met with at the bottom and limpet-like fishes (e.g., *Glyptosternum, Balitora*) or fishes with special modifications. (*Garra, Glyptothorax, Pseudecheneis*) occur on the rocks. The loaches and corps adhere to rocks like the limpets, with the ventral surface, inclusive of paired fins forming one large sucker, e.g., *Gastromyzon* of Borneo, the Indian loach *Baletora* of the eastern Himalayas and Assam hills (**Hora**, 1942).

Physico-chemically, the fast-water ecosystems resembles with cold, deep lakes. Water temperatures tend to be quite low, productivity is also quite low, and diversity is high. In the fast water ecosystem, the main control of productivity is the current, which seriously limits the amount and type of autotrophs production that can take place.

2. SLOWLY FLOWING WATER

A slowly flowing water ecosystem is a very different sort system from the fast streams. Because the flow is both slower and more likely to be laminar, the erosive power of the stream is greatly reduced, and smaller sediment particles (silt) and decaying organic debris, instead of being carried away by the stream, are deposited on the bottom. In addition to these, the slow streams have a higher temperature, consequently, planktonic organisms, especially proto, zoans, occur in large numbers in this ecosystem. The detritus-feeding benthos of slow water ecosystems include those which either live on the bottom, such as isopods (sowbugs), molluscs (*Sphaenius, Pisidium,* and *Anodonta dominata*), and mayfly and damselfly naiadas, or which burrow into the sediment, such as tubeworms, naiads of the burrowing mayflies, *Sialis* (alderfly), midge *Chironomus*, and several other insect larvae, as well as, clams, nematodes, snails and rotifers.



Net winged midge larva

Mayfly nymph

Caddisfly Larva

Fig. 8·6. Some inhabitants of lotic environment.

Swimming organisms are also abundant, including not only fishes. Such as carps, cat fishes, suckers, stingers, spoonbills, etc., which tend to be different species from those of fast-water areas, but also larger Crustacea such as amphipods (fresh-water shrimps). Finally, several insects spend most of their time at the surface of the stream. These includes forms such as water striders, water boatmen, backswimmers, and predaceous diving beetles. Zooplankton is abundant, including a rich assemblage of Protozoa and smaller Crustacea such as Cladocera (water fleas) and copepods. The richness of food afforded by slow streams attract a large number of reptiles (water snakes, crocodiles, turtles) and amphibians.

Plant life is also abundant in a slow-water ecosystem. It includes rooted vascular plants such as pond weeds and grasses, firmly attached aquatic mosses and large multicellular filamentous algae. Motile algae such as diatoms and flagellates may abound in the open water. In all, the primary productivity of slow-water ecosystem is higher than that of the rapid-water ecosystem, and the community is relatively less depandent on food materials from outside. Further, the detritus food chain consisting of organisms such as bacteria and fungi is much better developed in this community as the partially decomposed organic debris that comprises the main food source for these organisms accumulates in the mud bottom. In some slow-moving streams, in fact, the bottom muds contain more organic material than mineral fragments.

In slow-water streams oxygen concentration remains main limiting factor. The high level of animal activity, coupled with an active detritus food chain, can withdraw a large amount of oxygen from water of a slowly moving stream. In addition, the low level of turbulence means that less oxygen is incorporated into the water at the surface. Thus the dissolved oxygen content of a slowly moving stream is likely to be much lower than that of a fast- moving stream. This is commonly reflected in the fauna of the stream. Fishes tolerant of low oxygen levels such as carps and catfish are the most common fishes in slow water, while species with high oxygen demands, such as trout are found in fast water,

CHAPTER 9

AQUATIC ECOSYSTEMS : ESTUARIES AND MARINE COMMUNITIES

Waters of all streams and rivers ultimately drain into the sea ; the place where this fresh water joins the salt water is called an **estuary**. Estuaries are the transitional zones between the sea and rivers and are the sites of unique ecological properties possessing a characteristic biological make up. They are semienclosed coastal bodies of water that have a free connection with the open sea and within which sea water is measurably diluted with fresh water from rivers. Not all rivers open into estuaries : some simply discharge their runoff into the ocean. Estuaries differ in size, shape and volume of water flow, all influenced by the geology of the region in which they occur. As the river reaches the encroaching sea, the stream-carried sediments are dropped in the quite water. These accumulates to form **deltas** in the upper reaches of the mouth and shorten the estuary. When silt and mud accumulations become high enough to be exposed at low tide, **tidal flats** develop, which divide and braid the original channel of the estuary. At the same time, ocean currents and tides erode the coast line and deposit material on the seaward side of the estuary, also shortening the mouth. If more material is deposited than is carried away, then **barrier beaches, islands,** and **brackish lagoons** appear.

PHYSICO-CHEMICAL ASPECTS OF ESTUARIES

Current and **salinity**, both very complex and variable, shape life in the estuary, where the environment is neither fresh-water nor salt. Estuarine currents result from the interaction of a one-direction stream flow, which varies with the season and rain fall, with oscilating ocean tides, and with the wind. The salinity of estuaries varies vertically and horizontally and fluctuate amazingly between 0·5 to 35 per cent. Due to low salinlty fresh water has a lowet density than sea water (±1·00, as opposed to 1·03). Were there no tides in an estuary to mix fresh and salt water, the lighter fresh water would simply flow over the heavier sea water and dissipate in the ocean. However, the tidal action acts as a plunger to thoroughly flush the estuary and mix the fresh and salt water. This has several results. The water level in the estuary fluctuates regularly, unlike that of river. For this reason the habitat that is covered at high tide and uncovered at low tide is a prominent one in the estuary, and has no analogue in any purely fresh water ecosystem. Further, the the salinity is exceedingly variable and may change by a factor of ten over the course of a day at any location. At low tide, most of water passing through the estuary is fresh-river water, and the salinity is correspondingly low. At high tide, most of the water may be of marine origin, and the salinity correspondingly high. Flow may be somewhat stratified, or mixing may be incomplete, and the salinity at any time may vary considerably from one location to another. The intensity of current, and hence of the degree of mixing, is a function of the intensity of the tides and of the rivers flow rate. In other words, an estuary is an exceedingly variable environment. Further, salinity of estuaries remain highest during the summer and during periods of drought, when less fresh water flows into the estuary. It is lowest during the winter and spring, when rivers and streams are discharging their peak loads. No stenohaline organism (such as Echinodermata, Cephalopoda, and other molluscs) could hope to survive in the estuaries. Likewise, no organism that could not tolerate strong currents and the turbid water that results from strong currents could live there.

The temperatures in estuaries fluctuate considerably diurnally and seasonally. Waters are heated by solar radiation and inflowing and tidal currents. High tide on the mud flats may heat or cool the water, depending on the season. The upper layer of estuarine water may be cooler in winter and warmer in summer than the bottom a condition that, as in a lake, will result in a spring and autum overturn.

Anyhow, all estuaries have high productivity. As estuary's high productivity is exceeded among aquatic communities only by coral reefs. The reason is that although an estuary may be a harsh environment in some ways, it is not in others. Because the typical estuary is shallow and turbulant, the amount of dissolved oxygen tends to be fairly high although it may be low in bottom layers of those estuaries where water does not mix from top to bottom. More important, the tidal action acts to accumulate (concentrate) the nutrient and energy materials that wash in from upstream or, in some cases, that enter from the nutrient rich bottom waters of the sea. The mechanism of nutrient concentration is very simple—particulate nutrient material enters the estuary at its upper end, is carried seaward by the falling tide and is brought back through the estuary by the rising tide, and so on for several cycles. The length of time it takes from a nutrient particle to traverse the estuary is substantially greater than it would take for it to traverse a similar length of even the most slowly flowing river. Thus, the estuary acts as a nutrient trap, with an average nutrient level significantly higher than either the river or the sea that it connects. Likewise, the concentration of energy-rich organic materials remain high in estuaries.

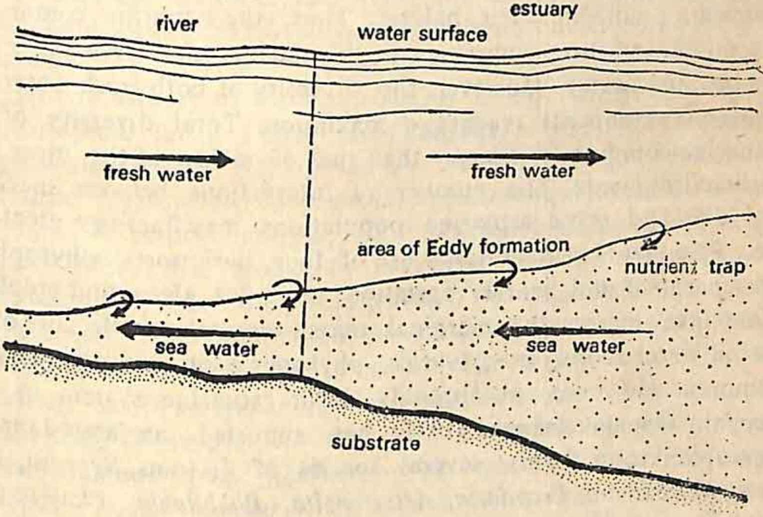


Fig. 9·1. Diagram showing formation of nutrient traps and horizontal turbulance or eddy.

The primary result of the concentration of nutrients and fixed carbon is a very high level of production within the detritus food chain. This has two aspects. First the nutrient material is broken down bacterially at a very high rate, and recycled back into soluble form. This allows a very high rate of gross primary production for estuarine plants. More important, perhaps, the amount of nutrient-rich organic detritus allows a level of productivity for detritus-eating animals much higher than could be maintained on the basis of the primary production by estuarine plants.

BIOTIC COMMUNITIES OF ESTUARIES

Carikker (1967) has classified the regions of estuaries into the **head**, where freshwater enters the estuary, **upper**, **middle** and **lower reaches** with increasing range of salinities and the mouth with salinity nearly equal to the sea. He has also classified the animals inhabiting the estuarine region into **oligohaline** (0·5 to 5 per cent),

mesohaline (5 to 18 per cent) in the upper reaches **polyhaline** (18 to 25 per cent) in the lower reaches, 25 to 30 per cent in the middle and **euhaline** (30 to 50 per cent) in the mouth of the estuary. **Krishnamoorthy** (1963) in fact reported that the extent of penetration of the polychaets *Marphysa gravelyi, Diopatra uariabilis, Clymene insecta, Loimia medusa, Glycera embranchiata, Onuphis eremita* into the Adyar estuary in Madras from the Bay of Bengal vary with varying salinities at constant temperatures.

Furthermore a estuary being a transitional zone between the freshwaters and seas is an ecotone and, therefore, typical estuarine forms are unique in their habitat. Thus, the estuarine community is a mixture of three components : the marine, the fresh water and the brackish water. However, the diversity of both fresh-water and marine components reaches a maximum. Total diversity of the estuarine community is lower than that of either of the more normal environments. The number of interactions between species is not high and some estuarine populations may fluctuate greatly in size. The plants of the estuary are of four basic sorts : phytoplankton, marginal and marsh vegetation, mud-flat algae, and epiphytic plants-growing on the marginal marsh vegetation. Because of the turbid water found in estuaries, phytoplankton are normally uncommon. However, in Hooghly-Matla estuarine system in west Bengal, **Gopalakrishnan** (1971) has reported an abundance of phytoplanktonic forms—several species of diatoms, *Synedra, Navicula, Rhizostoma, Fragilaria, Asterionella, Biddulphia, Planktoniella, Hemidiscus, Chaetoceros, Cyclotella, Stephanodiscus, Triceratium*; several species of green algae like *Pediastrum, Spirogyra, Eudorina, Tribonema, Closterium, Zygonema, Pandorina, Volvox, Chlorella*; and blue-green algae like *Microcystis, Oscillatoria, Anabaena*, and *Trichodesmus*. Most estuarine algae are of marine origin. Further, the most significant estuarine plants are marsh grasses such as *Spartina, Salicornia*, and *Scirpus*, as well as some submerged filamentous algae such as *Cladophora, Chara* and *Enteromorpha*. Very few animals feed on these plants directly, but a very large amount is consumed as detritus.

The estuarine animal communities include zooplanktons and other animals. For example, the planktonic animal forms of Hoogly-Matla estuary of India include flagellate protozoans such as *Euglena, Ceratium, Peridinium, Noctiluca* ; other protozoans such as *Difflugia, Arcella, Vorticella ;* rotifer species such as *Brachionus, Keratella, Asplanchna*, etc.; copepodes like *Diaptomus, Pseudodiaptomus, Cyclops* and *Paracalanus ;* cladocerans of the genus *Bosmina, Bosminopsis*

Ceriodaphnia, *Moina*, besides a number of isopods (**Gopalakrishnan,** 1971). All these forms remain confined to water and lead a pelagic existence. The best known eustarine animals are detritus feeders like oysters (*Ostrea* sp. of Lake Chilka), clams, lobsters, and crabs. Several insect larvae, annelid worms, molluscs, enter the estuary from the fresh-water, while, most marine phytoplankton, Crustacea, annelid worms, anemones and Bryozoa enter a estuary from marine ecosystems. For example, out of 130 species of fishes and 30 species of prawns of Hoogly-Matla estuary, several fishes such as *Hilsa, Harpodon, Mugil, Trachyurus*, etc., migrate from sea in to the mouth of the estuary, to form important fish catches, while some like palaemonid prawns are fresh-water inhabitants and come to live in estuaries.

Adyar estuary of Madras coast is found rich in invertebrate and vertebrate fauna (**Aiyar** and **Panikkar**, 1937). The common invertebrates of this estuary are sea anemones (*e.g.*, *Phytocoetes gangeticus*, *Phytocoeteopsis ramunnii*, *Stephensonaetis ornata*, *Pelocoetes exul*, *Bolocractis gopalai*, etc..) ; hermaphrodite nereids (*e.g.*, *Lycastis indica*) : the tubicolous polychaet *Diopatra variabilis* ; the burrowing polychaet *Marphysa gravelyi*, the oligochaet *Pontodrilus bermudensis* ; the mysids *Rhopalophthalmus egregius* and *Mesopodopsis orientalis* ; the crabs *Uca annulipes*, *Uca triangularis*, *Neptunus pelagieus*, *Scylla serrata*. *Veruna litterata*, *Sesarma tetragonum* ; the hermit crabs *Clibonarius olivaceus* and *Clibanarius padavensis*, and several molluscs (*e.g. Ostraea arkanensis*, *Modiolus undulatus*, *Meretrix casta*, *Cuspidaria cochinensis*, *Stenothyria blanfordiana*, *Amnicola stenothyroides*, *Potamides cingulatus*, *Styliger gopalai* and *Bursatella leachii*) The vertebrate fauna of Adyar estuary includes the fishes like *Etroplus maculatus*, *Etroplus suratensis*, *Acentrogobius viridipunctatus*, *Acentrogobius neilli*, *Panchax parvus*, *Aplocheilus melastigma*, and mud skipper *Periophthalmus koelreuteri* and snakes such as *Natrix piscator* and *Cerberus rhyncops.*

In short, the estuarine ecosystem is a complex and interesting one. It is also very vulnerable environment, because it has served as conduits for shipping and as sites for cities throughout the history of man. The organisms that inhabit an estuary are adapted to a vastly changing environment, but because estuaries are strategically located, man-made alterations to their ecosystems are substantially greater than in almost any other ecosystem.

MARINE ECOSYSTEMS

The marine environment of seas and oceans is large, occupying 70 per cent of the earth's surface. The volume of surface area of marine environment lighted by the sun is small in comparison to the total volume of water involved. This and the dilute solutions of nutrients limits production. It is deep, in places nearly 4 miles. All the seas are interconnected by currents, dominated by waves, influenced by tides and characterized by saline waters. Not only the seashore and banks which are the homes of many organisms but the open ocean, many hundreds of miles away from land, supports plant and animal communities of great diversity and complexity.

PHYSICO-CHEMICAL ASPECTS OF MARINE ENVIRONMENT

In the marine environment, the most important physical factors which influence marine life are light, temperature, pressure, salinity, tides and currents.

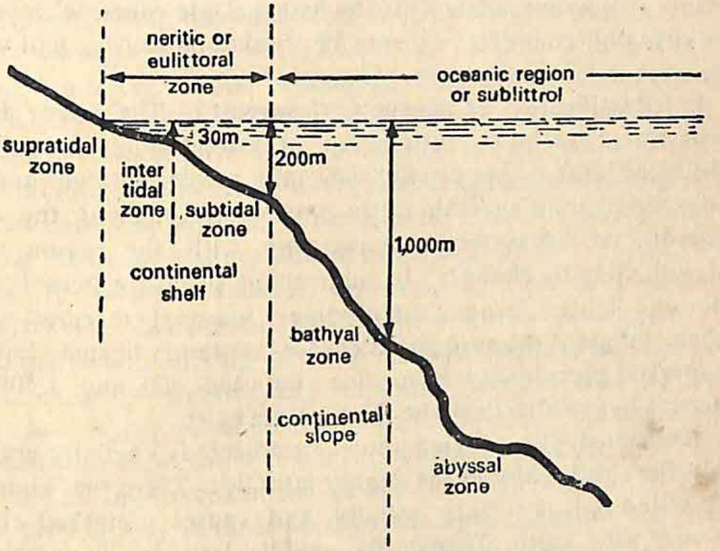
1. **Light :** Light is a very significant factor in regulating the pattern of distribution of marine animals and it contributes significantly to organic production. The autotrophic primary producers exploit the light energy in the photosynthetic production of food for primary macroconsumers of marine ecosystem. The amount of light exploited in photosynthesis depends on intensity of light and turbidity of water. For example, a ten meters deep turbid coastal zone receives an equal amount of light energy as a hundred meters deep clear oceanic zone, but the maximum intensity at a ten meters coastal water is greater. Light determines diurnal migrations of marine organisms, and it also regulate colour pattern of marine animals. The deep sea fauna which lives in total darkness exhibit either colourlessness or uniform colouration. It is also somehow related with the development of visual sense organs as shown by absence of functional eye in deep-sea animals.

2. **Temperature :** The range of temperature in sea is far less than that on land. Arctic waters at 27°F are much colder than tropical waters at 81°F, and currents are warmer or colder than the waters through which they flow. Seasonal and daily temperature changes are larger in coastal waters than on the open sea. The surface of coastal waters is the coolest at dawn and the warmest at dusk. In general, sea water is never more than 2° to3° below the freezing point of fresh water or higher than 81°F. At any given place the temperature of deep water is almost constant cold, below the freezing point of fresh-water. Unlike fresh-water, sea water does not have a density maximum at 4°C ; rather it becomes continuously denser as it gets colder.

3. **Pressure :** Pressure in the ocean varies from 1 atm at the surface to 1,000 atm at the greatest depth. Pressure changes are

many times greater in the sea than in terrestrial environments and have a pronounced effect on the distribution of life. Certain organisms are restricted to surface waters when the pressure is not so great, where as other organism are adapted to life at great depths. Some marine organisms, such as the sperm-whale and certain seals, can dive to great depths and return to the surface without difficulty.

4. **Zonation of marine environment :** Just as lake exhibit stratification and zonation, so do the seas. The ocean itself is divided into two main divisions, the **pelagic**, or whole body of water, and the **benthic**, or bottom region. The pelagic region is further divided into two provinces ; the **neritic**, water that overlies the continental shelf, and the **oceanic provinces**. The **continental shelf** is the underwater extension of the continent and it generally extends to a depth of roughly 125—200 m. The edge of the continental shelf may be within a few kilometers of the shore, or it may be several hundred kilometers from shore. From the edge of the continental shelf there is a more rapid descent, the **continental slope;** to the broad flat **abyssal plain** that underlies most of the ocean at a depth of 4,000—5,000 m. On the abyssal plain, there are extensive mountain ranges, or **midoceanic ridges,** some of which have tips projecting above sea level. In addition, there are very deep troughs, which drop down below 11,000 m. below sea level. Life exists from the very top of sea to the bottom in virtually all areas, although its abundance is exceedingly variable.



Fig, 9·2. Different zones of sea.

The benthic life zones are defined in terms of these physical subdivisions. The **littoral**, or **intertidal** zone, is the zone between high tide and low tide levels. The **sublittoral** extends from the low tide mark to the edge of the continental shelf, with the **bathyal zone** comprising the continental slope. The **abyssal zone** includes the abyssal plains, and the **hadal zone** includes any life in the deep trenches below 5,000 m.

The pelagic zone is divided into three vertical layers or zones : from the surface to about 200 m is the **photic zone**, in which there is sharp gradients of illumination, temperature, and salinity. The region below this zone is called **aphotic zone**. From 200 to 1,000 m where very little light penetrates and where the temperature gradient is more even and gradual and without much seasonal variation, is the **mesopelagic zone** of aphotic zone. It contains an oxygen-minimum layer and often maximum concentrations of nitrate and phosphate. Below mesopelagic is the **bathypelagic zones**, where darkness is virtually complete except for bioluminescence, and where temperature is low and pressure is great,

5. **Stratification of marine environment :** The upper layers of ocean water exhibit a stratification of temperature and salinity. Depths below 300 m are usually thermally stable. In high and low latitudes temperatures remain fairly constant throughout the year. In middle latitudes temperatures vary with the season, associated with climatic changes. In summer the surface waters become warmer and lighter, forming a temporary seasonal thermocline. In subtropical regions the surface waters are constantly heated, developing a marked permanent thermocline. Between 500 and 1,500 m a permanent but relatively slight thermocline exists.

Associated with a temperature gradient is a salinity gradient or **halocline**, especially at the higher latitudes. There the abundant precipitation reduce surface salinity and causes a marked change in salinity with depth. Thus in the middle latitudes in particular, the two produce a marked gradient in density. Water masses form density layers with increasing depth. Because density of seawater does increase in depth and does not reach its greatest density at 4°C as with fresh-water, there is no seasonal overturn. This results in a normally stable stratification of density known as the **pycnocline**. Because there are marked changes in temperatures with depth in the open ocean and thus with density, the pycnocline often coincides with the thermocline. Below the pycnocline is the deep zone which is oxygen rich, cold and comprises 80 per cent of the ocean.

6. **Salinity :** The marine animal life has specific osmoregulatory adaptation for high saline sea waters. The absence of many animal species in marine environment has been related to their inability to tolerate the high salt contents of sea water. Except few insects such a *Halobates* and shore collembolans like *Isotoma* and *Sminthurus*, most insects do not occur in marine ecosystems. The salinity of marine water fluctuates from place to place and it is caused due to the dissolved salts such as chlorides of sodium, potassium, calcium and magnesium, and also the sulphates of calcium and magnesium.

7. **Currents and tides :** Sea water is never static and waves, currents, and tides are the regular features of sea water. All these phenomena are controlled by winds, cosmic forces and varying water densities. Most world-wide water currents occur at the surface and at great depths of sea water. These currents determine the interchange between the surficial and deep water masses, as well as horizontal movements. Both the horizontal and vertical movements of ocean water are significant, but for different reason. Within a 'given current, such as warm Gulf stream, for instance, the water mass retains its identity for great distances, and the warm-sea community ranges far north of what have been anticipated as its northernmost limits. In addition, the climate of terrestrial ecosystems is strongly 'affected by the nature of adjacent water masses. The prevailing winds blow across the ocean and are heated or cooled by the waters they traverse. In marine ecosystems, however, the oceanic current system controls the distribution of productivity of marine communities through vertical mixing of water masses. Because most of the ocean is permanently stratified, any essential nutrient that settles out of the upper layers, either as an inorganic mineral or as organic detritus, is not returned to the upper layers at the same location. This had led to such an improverishment of the surficial waters of the oceans that productivity in most parts of the open oceans is about the same as that of desert, because of the very low concentrations of nutrients, especially phosphorus. At the same time, the lowest waters of the ocean are nutrient-rich. There are certain regions in the world, notably at the west coasts of continents and in subpolar latitudes in both hemispheres, where deep currents rise to the surface. These are called **zones of upwelling,** and even though their waters are very cold, they are sites of intense production because of their relatively high concentration of nutrients. Nutrients are then cycled back to the rest of the ocean via surface currents.

Tides are water movements which are caused by some astronomical factors. They represent a rhytmic rise and fall of water and often waves of long wave lengths characterize the process. The chief astronomic force behind the tidal rhytm is the attraction of the moon and sun depends on the movement of earth in relation to the moon and the sun. Tides influence the sea-shore fauna variously, as low tides expose the shore and high tides flood the substratum.

MARINE COMMUNITIES

The sea biota is not abundant but contains well marked diversity. Every major group of algae and almost every major group of animals can be found some where in the oceans. The only striking omissions are the vascular plants and insects, which are abundant in estuaries but which have few or no marine representatives. The marine biotic commuities can be studied separately for different life zones of the ocean as follows :

A. BIOTIC COMMUNITIES OF OCEANIC REGION

The oceanic region or pelagic zone is less rich in species and numbers than the coastal areas, but it has its characteristic species. Many of these are transparent or bluish and since the sediment-free water of the open sea is marvelously transparent, these animals are nearly invisible. Animals that are too thick to be transparent frequently have smooth shiny and silvery bodies which make them invisible by mirroring the water in which they swim. Further, the animals of the pelagic zone of ocean encounter stable and uniform environmental conditions due to the continunity of the waters of the sea. This continuity of sea waters causes the individuals of the open ocean to stay away temporarily or permanently from any solid objects, and they are provided with different locomoter organs. However, the planktonic forms lack a locomoter organ and float freely in the vast expanse of the sea.

1. Biotic communities of pelagic zone : The pelagic plankton also called **epiplankton** are exceedingly diverse. **Phytoplankton** includes diatoms and dinoflagellates, which together produce most of the organic carbon in the sea (and most of the oxygen in the atmosphere), as well as other forms of golden-brown algae and flagellated green algae. Some seaweeds, such as the large brown algae *Sargassum*, may have a floating stage. The **zooplankton** of pelagic zone include representatives of every major phylum and most minor phyla, either as permanent members of the plankton community (**holoplanktonic forms**) or as transients during their larval stages (**meroplanktonic forms**). Common among permanent planktonic forms are the Forminifera and Radiolaria, arrow worms (*Sagitta*), certain annelid worms, swimming snails, jelly fish and most abundant of all the crustaceans such as shrimps, copepods and cladocerans. Among the temporary zooplankton are the larva of larger animals from all marine environments and even some fresh-water environments. For example, in the zooplanktons of inshore waters of Mandapam (South India) **Prasad** (1956) reported following animal species–

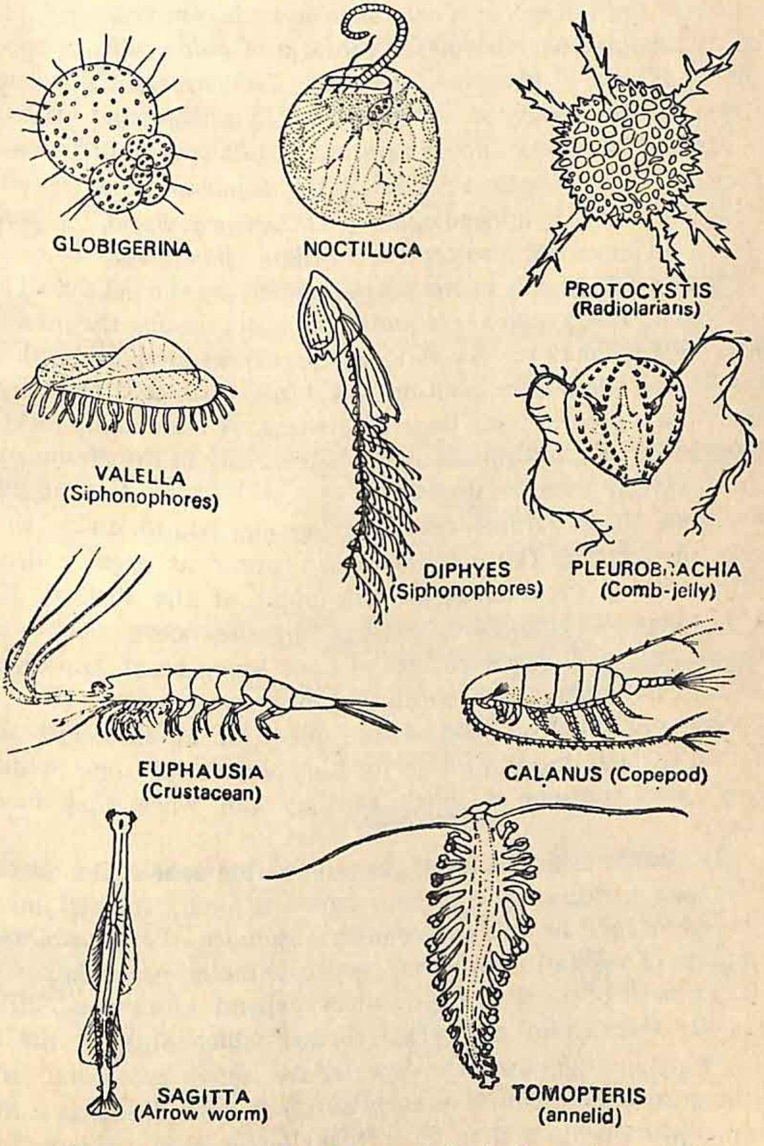


Fig. 9·3. Certain holoplanktons of pelagic zooplanktons.

flagellate protozoan *Noctiluca miliaris* ; larval forms of coelenterates like *Planula, Ephyra, Semper's* larva, and *Cerianthus* larva ; medusae of certain coelenterates such as *Bougainvillia, Obelia, Charybdea, Rhizostoma* and *Rhopalina* ; ctenopheres like *Pleurobrachia* and *Beroe* ; larvae of many polychaet annelids and annelids such as *Tomopteris, Alciopa* and *Autolytus*, several species of chaetognaths like *Sagitta* and *Spadella* ; heteropod and pteropod molluscs like *Carinaria, Pterotrachea, Cliona, Creseis*; larvae of echinoderms such as bipinnaria, ophiopluteus, echinopluteus, auricularia; tornaria of *Balanoglossus*; species of copepods like *Acartia, Calanopia, Labidocera, Centropages, Paracalanus, Canthocalanus, Acrocalanus, Eucalanus* and *Microsetella* ; larvae of decapod *Lucifer* ; protochordate species of Larvacea, Thaliaceae and Ascidiaceae such as *Thalia democratica, Jasis zonaria, Salpa cylindrica* ; appendicularian-*Oikopleura diocia, O. parava* and *O. cephalocera* and also cephalochordate *Amphioxus*.

The largest animals in the pelagic region are the nekton. These include cephalopods such as saquid and nautili among the invertebrates, as well as many marine vertebrates, such as bony fishes, sharks sea turtles and whales. In addition, sea birds also feed on many of the same food types as these large carnivores. Air-breathing nekton, such as the turtles, and whales, are found mainly in the photic zone, but fishes extend from the sea surface to the bottom. Certain fishes such as tuna, shark, sardine, mackerel, herring, bonito, and anchovy live near the surface. Those fishes which occur at greater depths are often grotesque and unlike any fish found at the surface. They tend to be small—15 to 20 m is large for the ocean deeps—and they are exceedingly dispersed. Many have luminescent appendages with which to lure prey, or mouth that look several sizes too large for the rest of the body. Food is not plentiful in the deep waters of the sea, so these fishes must go for long periods of time without food, and then consume as much as they can when they have a chance.

(ii) **Biotic communities of abyssal benthic zone :** The abyssal benthic zone or deep sea of oceanic region is pitch dark and universal absence of light in this environment excludes the possibility of any growth of vegetation or other photosynthetic organisms. Consequently, most of the deep sea dwellers depend upon the detritus (dead body and excreta of surface forms) which sink to the sea bottom while a large number of species are active predators. However the deep ocean benthos is surprisingly diverse. Food is a little more plentiful on the bottom than it is in the deep waters of the ocean, because the bottom sediments are the ultimate resting place for all detritus raining out of the upper layers (oceanic surface and pelagic zones). The bottom of the sea is a soft ooze, made of the organic remains and shells of Foraminifera, Radiolaria, and other animals and plants. Sea cucumbers, brittle stars, crinoids (sea lilies), sea urchins, certain benthic fishes, and several types of crustaceans, as well as sea anemones, clams, and similar animals are all found on

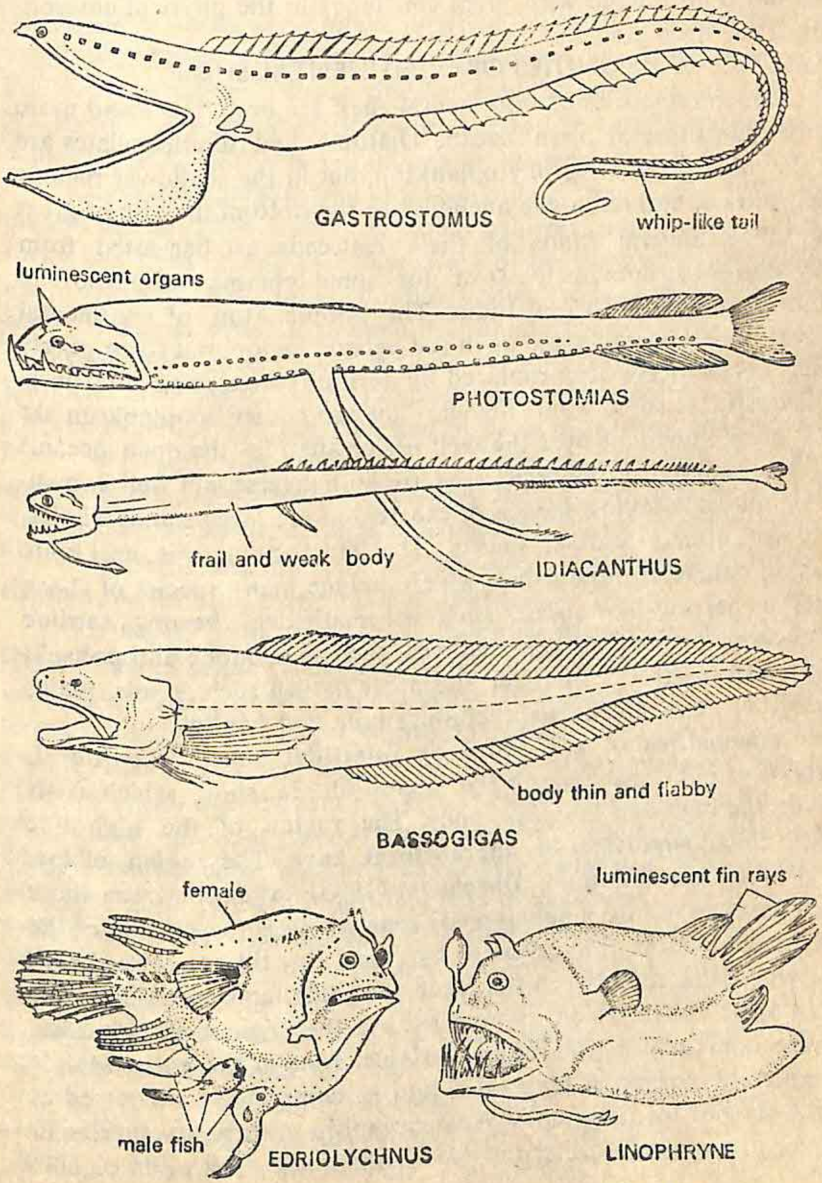


Fig. 9·4. Fishes of the deep waters of the ocean.

the bottom, not only on the abyssal plains, but some even at the bottoms of the deepest ocean trenches. Many of them are detritus feeders but a large number of them are carnivores. In fact, the biomass of carnivorous brittle stars is often higher than that of the detritus feeders that serve as their food source ; however, their metabolic rate is much lower. The great diversity of sea bottom fauna has been related with great constancy in the physical environment of the deep sea.

B. BIOTIC COMMUNITIES OF CONTINENTAL SHELF

The communities of continental shelf are both richer and more diverse than those of open ocean. Diatoms and dinoflagellates are still the most productive phytoplankton, but in the shallower regions green, brown, and red algae anchored to the bottom may be of great importance. Several kinds of these seaweeds are harvested from rocky shores as human food or for some commercial purpose in eastern countries, USA and India. The zooplankton of continental shelf are generally the same as in the pelagic region, but some purely pelagic species have been replaced by neritic species, and the overall diversity is some what higher. The temporary zooplankton are much more abundant over the shelf region than in the open ocean.

The neckton of the **neritic sea** are both diverse and well known. The significant neckton species of the region are large squid, whales, seals, sea otters, and sea snakes. The most numerous necktonic forms, of course, are the fishes, which include many species of shark as well as herring-like species such as menhaden, herring, sardine and anchovy ; cods and their relatives, such as haddock and pollack; salmon and sea trout ; flounder and other flatfish such as sole, plaice and halibut ; and mackerels, including tuna and bonito.

Communities of sea shore or **intertidal zone :** The littoral, intertidal or eulittoral zone, is the region of sea shore which exists between the high and low tide lines. The region of the high tide mark is called **supratidal** or **supralittoral zone**. The region of low tide is called **subtidal zone**. **Davenport** (1903) has divided sea shore or intertidal zone into a **submerged zone** which is the portion of the shore below the low tide exposed by very low tides, a **lower beach** occupying the area between the mean low tide and mean **high tide** and an **upper beach** which is reached by the **highest of high tides. The** intertidal zone is the most variable **zone in the entire sea. It** is completely covered at high tide, and is **completely uncovered at** low tide except for tide pools. Any organism **that is to survive in** the intertidal must be either resistant to **periodic dessication or able**

to burrow to water level. For example intertidal polychaets escape desiccation by resorting to a tubicolous mode of life whereby they can resist desiccation by retaining sufficient moisture till the advent of the next wetting. Barnacles can survive desiccation by remaining in a state of suspended activity during dry periods. Many plants of sea shore contain jelly-like substances such as agar, which absorb large quantities of water and retain it while the tide is out. Further, the majority of shore animals utilize oxygen dissolved in water and when the low tide exposes them periods of drought, they utilize the oxygen stored in the blood plasma, *e.g*,, nereid like, *Arenicola*. Barnacles achieve this by enclosing on air bubble between the shells.

One of the outstanding characteristics of this region is the ever present action of the waves, and the organisms living on a sandy or rocky beach have lad to evolve ways of resisting wave action. The many seaweeds have tough pliable bodies, able to blend with the waves without breaking, while the animals either are encased in hard calcareous shells, such as those of mollusks, Bryozoa, starfish, barnacles and crabs, or are covered by a strong lethery skin that can bend without breaking, like that of the sea anemone and octopus. Many sedentary shore animals (*e.g.*, sponges, tunicates, etc.) have special modes of adhesion which keep them firmly attached to the substratum. However, animals of sandy beaches escape wave action by taking burrowing mode of life, because, these lack a hard substratum for the attachment of the animals.

The biota of intertidal zone also have to over come the wide fluctuations in salinity and temperature. Thus, like the estuary, this variable environment is a zone in which an organism must be adapted to a broad range of environmental conditions. Like the estuary also, it is an area of very high productivity with a simple community, many of whose members may be exceedingly abundent. The diversity of biota of intertidal zone is determined by nature of substratum whether loose sand or mud or rocky coast. Ecologists have recognized three major types of intertidal zones or seashores, namely, **rocky**, **sandy** and **muddy**. **Eltringham** (1971) has included a fourth type of sea shore, the **pabble shore** in this classification. Each type of sea shore possess specific biota each of which remain specificially adapted for its peculiar habitats. Here we will discuss only rocky shore and sandy beach habitats.

1. Biotic communities of rocky shore : The rocky shore presents solid substratum for the attachment of many sessile animals which often remain abundant here. The animals which are sedentary and inhabit rocky shore are limpets like *Patella*, *Haliotis*, *Fissurella*, and oysters, barnacles, tunicates and bryozoans. Sessile organisms like the sponges, the colonial hydrozoans, anthozoans like *Gammaria* and *Zoanthus* attached to rocks. Certain animals such as some sponges, annelids and molluscs either bore the soft rocks like limestone or seek protection in the cervices of hard rocks. All these sedentary sessile animals are adopted for filter feeding.

Further, all these animals of rocky shore occurs in successive zones. At the uppermost end is a zone of bare rock marking the transition between land and sea. Next is a spray zone with dark patches of algae on which the periwinkles (*Littoria*) graze. Below this is the zone called barnacle zone regularly covered by the high tide ; rocks in this zone are encrusted with acorn barnacles, limpets and mussels (*e.g.*, *Mytilus*). This zone is a vulnerable zone being exposed to the brunt of wave action and active predation by starfishes and gastropods. The mussels act like hard substratum for tunicates, sponges and small muscles. The next one is the zone of oyesters is less vulnerable and includes green algae (*Enteromorpha* and *Ulva*) and barnacles. The next zone includes mussels, *i.e.*, boring bivalves, which remain within cervices with exposed siphons only to be protected from waves and predation, The chief species of borer bivalves are *Pholas*, *Martesia*, *Hiatella*, *Tridacna*, etc. Besides bivalves a variety of filter feeder bryozoans, and brachiopods and tubucolous polychaets like *serpulids*, *terebellids*, *sabellids* and *cirratulids* which live in tubes are the chief inhabitants of this zone. The subtidal zone includes red algae, brown algae (Laminarians and fucoids), sea anemone, sea urchin, corals, etc.

For example, the Okha coast of Gujrat in India is a typical rocky sea coast which has well defined fauna and flora (**Gopalakrishnan**, 1970). Dominant weeds of subtidal zone of Okha coast are *Sargassum*, *Dictyopteris*, *Graciliaria*, *Padina*, *Ulva*, *Polysiphonia*, etc. This subtidal zone also contains sea urchins, serpulid tubes of species *Pomatoleius crosslandi*, and mollusc species like *Trochus radiatus*, *Cypraea arabica*, *Thais alveolata*. The upper limit of the dense weed growth of subtidal zone marks the lower end of eulittoral or intertidal zone, where occur a dense clusters of *Crassostrea cucullata* and *Littorina* sp. The intertidal zones includes three subzones, *i.e.*, the subzone of patchy weed growth ; 2. the subzone of limpets like *Sellana radiata* and barnacles ; and 3. the subzones of oysters and barnacles. The supratidal zone is inhabited by green algae and molluscs. Chlorophyceae like *Enteromorpha*, *Ulva*, *Bryopsis*, *Codium*, *Halimeda*, *Caulerpa*, *Dictyosphaeria* and *Cladophora*, Phaeophyceae like *Padina*, *Sargassum*, *Colpomenia*, *Iyengaria*, *Spathoglo-*

ssum, *Dictyopteris* and *Turbinaria* ; Rhodophyceae like *Gracilaria*, *Hypnea*, *Acanthophora*, *Polysiphonia*, *Cryptonemia* are the chief algae of the area. The common animals of this area are coelenterates species *Stoichactis*, *Ixalactis*, and *Gyrostoma* ; Nereid like *Eunice*, *Tubifex* ; molluscs like *Chiton*, *Nerita rumphii*, *Cypraea integerrimus*, *Pilumnus vespertilio*, seaweed grazer (nudibranch) molluscs, *Aplysia benedicti*, *Onchidium*, *Elysia grandifolia*, *Eolis*, *Doris* and floating mollusc *Janthina*, etc. The midlittoral reef community of Okha coast consists of fishes like *Epinephelus*, *Petrachus*; the crab *Pilumnus vespertilio*, the annelid *Eurythoe complanata* and molluscs like *Murex*, *Bursa*, etc. Rock cervices of intertidal zone harbour within them crabs like *Atergatis*, *Grapsus*, *Pilumnus*, *Matuta*, *Charybdea*, *Gelasimus* ; squillids like *Sesarma* and *Gonodactylus* ; coelenterates like *Stoichactis*, *Ixalactis*, *Zoanthus*, *Lobophytum* ; the hydroid species like *Lytocarpus*, *Sertularia* and *Plumularia* ; and annelids like *Sepula*, *Polynoe*, *Eurythoe*, *Sabella*, etc.

(ii) Biotic communities of sandy shore : The sandy shore may be even more harsh than the rocky shore. It is subjected to all the extremes of the latter (temperature, salinity, turbidity, wave action, etc.) plus inconvenience of a constantly shifting substratum. The last makes life on the surface almost impossible ; life has retreated below the surface. Generally sandy beaches are characterized by gentler wave action. Because of the prolonged time taken for drying up, these beaches are suitable for animal life. Decaying seaweeds and dead remains of animals result in the addition of organic matter to the sand. The coastal subsoil water is the environment of a special interstitial brackish water fauna. Most of the interstitial organisms are small, elongate, vermiform with transparent bodies. They have no eye but possess well developed adhesive organs and sense organs. They are negatively phototactic and gregarious in habit. They may be herbivore, carnivore, omnivore or detritus feeder. Large animal forms which are few in number prefer coarse sand grains and smaller one which very abundant, prefer finer sand. The principal animal groups of interstitial water are the Nematoda, Turbellaria, Annelida, Gastrotricha and Acarina. Certain animal groups such as Protozoa, occur sporadically. The top 20 cm of sand between low and mid-tide levels of the beach is occupied by the inhabitants such as Hydrozoa, Turbellaria, Nemertina, Rotifera, Archiannelida, Polychaeta, Ostracoda, Halacaridae and Nudibranchiata. Species of Gastrotricha, Kinorhyncha, and Isopoda occur at mid-tide levels preferably in deep layers of sand. Oligochaets are sporadic and are found at different levels. Harpactcoid copepods remain restricted to mid tide level.

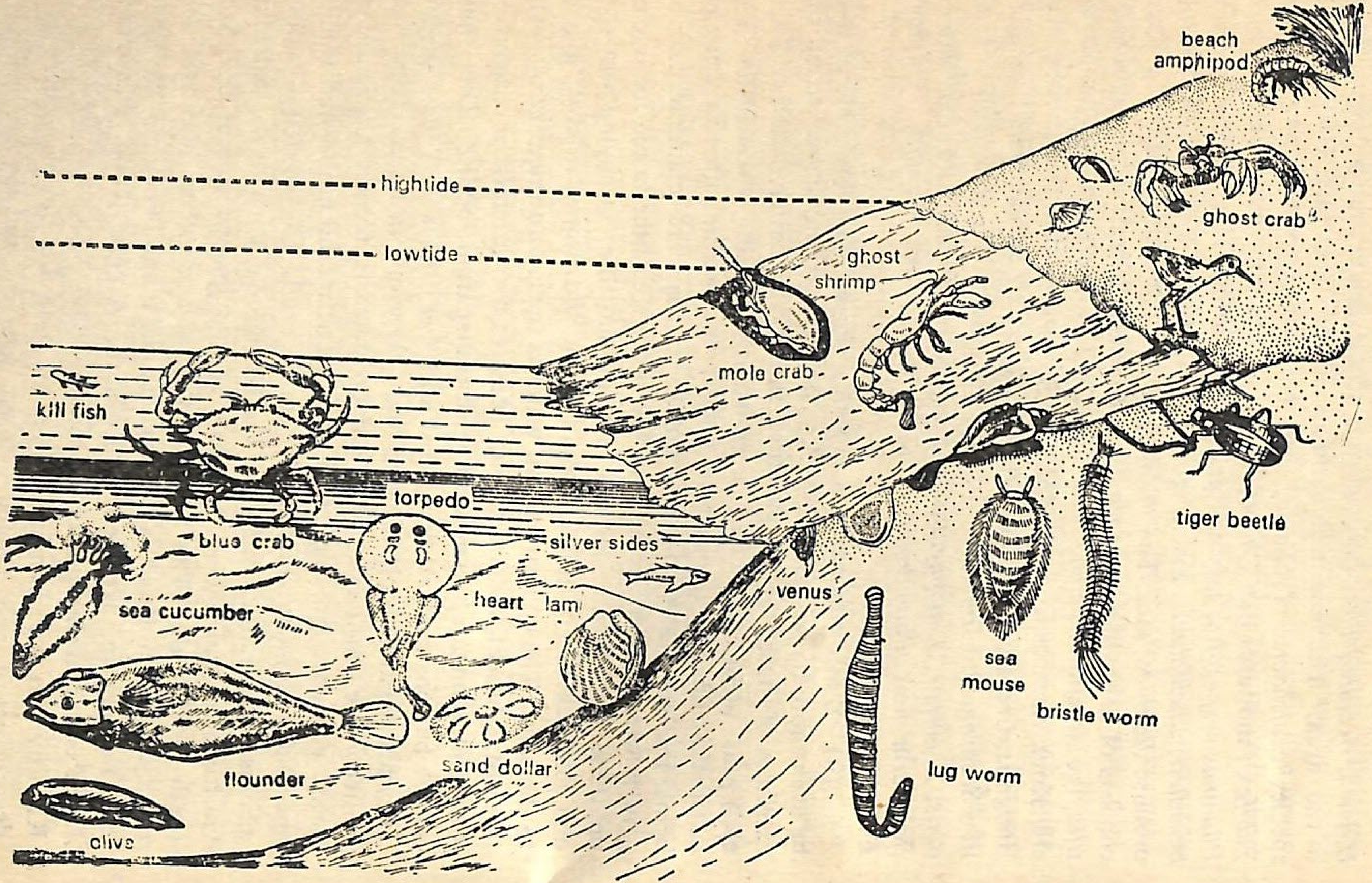


Fig. 9·5. Life on a sandy ocean beach along the Atlantic coast.

Tardigrades occupy the region between mid-tide and high-tide. Thus, sandy beaches also possess characteristic successive zones or zonations of animals.

For example, according to studies of **Ganapathy** and **Rao (1959)** sandy beach fauna of Visakhapatnam coast though lacks or contains small number of tubicolous polychaets and Crustacea due to very unstable substratum, but include following animal species—spionid *Prionospio krusadiensis*, *Aricia* and *Lumbriconeries* all of which possess the capacity to secrete mucus and formation of cover of sand grain over the body for protection, *Glycera lancadivae*, *G. alba*, *Nerina bonnieri*, *Pisionidens indica*, *Pisione complexa* and archiannelids *Saccocirrus minor* and *Protodrilus* also occur. The crustacean fauna of this zone includes *Emerita asiatica*, *Albunea symnista* (burrowing), amphipod species *Harpinia* sp., isopod *Sphaeroma walkeri*, mysid shrimp *Gastrosaccus spinifer*, hermit crabs *Clibanarius aretheusus* living within the shells of *Thais* and *Cerithium*, the eight-oared swimming crab *Matuta victor*, the spider crab, *Philyra scabruescula*, *Ocypoda platytarsis* and *O. macrocera*. Lamellibranchs like *Donax cuneatus* and *Pamphia textile*, burrowing snails like *Sinum neritoideum*, common gastropods like *Oliva gibbosa* and *Terebra* sp., *Bullia vittata* are also found along the coast of Visakhapatnam. This beach also contains eel *Ophichtys orientalis* and siphonophore coelenterates like *Physalia*, *Velella* and *Porpita*; and medusae like *Aequoria* and *Chiropsalmus*.

CORAL REEF AS A SPECIALIZED OCEANIC ECOSYSTEM

Coral reefs are the specialized ecosystems of ocean which are among the most productive of all ecosystems anywhere, with a diversity equalled only by tropical rainforests. The reef environment is very rugged one because it is constantly subject to the pounding of the waves, and parts of the reef are often above water at low tide. But reef is also a very rich environment for those species that can withstand the physical pounding of water. The amount of oxygen is very high. During the day, it may reach 250 per cent of saturation because of the production of oxygen by algae in the reef structure. Likewise, the tremandous amount of CO_2 produced by the metabolism can be carried off before it becomes too high.

Reefs can be found wherever a suitable substrate exists in the lighted waters of the tropics, away from areas of continental sediments which would tend to bury the reef in mud or cold upwellings which would tend to lower the temperature too much. They may form **barrier reefs** (*e.g.*, barrier reef in Australia which contains

canal or lagoon between them and coast) adjacent to continents ; **atolls** or ring-shaped or horse-shoe-shaped islands on the top of submarine heights, or **fringing reefs**, as in Mandapam, Appa Islands and Hare Islands. In all modern reefs, the main reef structure is formed by madreporarian corals of following families-Poritidae (*Porites minicoiensis, Porites mannarensis*), Acroporitidae (*Acropora intermedia*), Astraeidae and Milliporidae. Secretions of calcareous algae go into the building up of reefs. Equally important are calcareous Bryozoa, lamellibranchs and gastropod molluscs and Forminifera, which become significant elements in the total reef structure. Although the name 'coral reef' implies that corals should be the most abundant organism, algae of many sorts comprise over three times the biomass of the corals. In addition, the calcareous algae are not only producers ; their skeletons act to cement the entire reef to make it more resistant to the pounding surf.

Coral reef normally exist in water with mean temperature 20·5°C, but they can withstand very high temperatures. The growth of coral reef is influenced by salinity and reduced tides. Moderate water movement around the coral reefs help in the circulation of food.

BIOTIC COMMUNITIES OF CORAL REEF

Coral reef ecosystems harbour a abundant and well diverse biota. The well known Krusadi Island is the coral island of gulf of Manaar. It's dominant corals are *Porites, Montipora, Poecilopora, Acropora, Madrepora, Favia, Symphylia, Psammocora, Platygyra, Merulina* and *Leptastrea*. In the Krusadi area a luxuriant growth of sea weeds such as *Sargassum, Caulerpa, Turbinaria, Spatoglossum, Gracilaria, Ulva, Enteromorpha, Chaetomorpha* and *Polysiphonia*. The abundant sponges of this reef are *Spirastrella incorstans* and *Callyspongia fibrosa*. The other inhabitants of this reef are following —hydroid coelenterates like *Syncoryne, Sertularia, Eudendrium, Pennaria, Tubularia, Thyroscypus, Plumularia*; alcyonarians like *Clavularia, Alcyonium, Lobophytum, Sclerophytum, Telesto;* zooantharians like *Zoanthus, Gemmaria;* polychaet annelids like *Nereis, Polynoe, Eunice, Lepidonotus, Iphion, Eurythoe, Hesione*; sipunculid species like *Dendrostomum, Aspidosiphon* and *Phascolosoma*; molluscs like *Doris, Dendradoris, Acanthochiton, Ischnochiton, Haliotis, Emarginula, Trochus, Turbo, Nerita, Natica, Cypraea, Thais;* and echinoderms like *Holothuria atra, H. Scabra, H. edulis* and starfish *Proteaster lincki*.

Beautifully pigmented fishes like *Holocentrus, Lutianus* sp., *Pomacanthoides, Chaetodontopsis, Chaetodon, Linophora, Thallasoma* and *Zanclus* and the eels *Gymnothorax undulatus* and *G. punctatus* are commonly frequent in the coral reefs. These inhabitants of coral reef community, when exposed to low tides are subjected to predation by large number of birds like the crested tern *Sterna bergii*, golden plover *Pluvialis dominica fulva*, etc.

According to **Clapham, Jr.** (1973) the great productivity of reefs is obviously caused by something more than the abundance of light and oxygen. He considers nutrient cycles which runs very quickly and efficiently between the components of reef ecosystem to be main cause of great productivity of reef ecosystems. In fact, no organic matter is incorporated permanently into the sedimentary system portion of reef. The conditions of rapid nutrient cycling allow a mechanism by which the natural paucity of nutrients in the ocean can be effectively circumvented. It may also allow a gradual increase in nutrient availability by incorporating the nutrients of the non-reef organisms that wash into the reef, while still continuing to prevent the reef's own nutrients from being lost to the deeper seas.

CHAPTER **10**

TERRESTRIAL ECOSYSTEMS

Only about a quarter of the earth's surface is dry land, yet the complexity and variegation of terrestrial ecosystems are much greater than those of aquatic ecosystems. There is no unifying theme in terrestrial ecosystems analogous to the physical properties of water. Rather, the variety of climates, the diversity of the lithosphere, and heterogeneity of terrestrial biotic communities all conspire to give rise to such a variety of themes that they are woven together in nature to give an incalculable diversity of biotic communities and terrestrial ecosystems.

PHYSICO-CHEMICAL NATURE OF TERRESTRIAL ECOSYSTEMS AND THEIR COMPARISON WITH AQUATIC ECOSYSTEMS

An aquatic system is essentially a **single-phase system**, where water sets the tone for entire habitat. A terrestrial ecosystem, on the contrary, is a **three-phase system**, where the characteristics of the habitat are a function of the atmosphere and climate, the soil, and the biotic community itself. The atmosphere is the source of oxygen for animals and carbon dioxide for plants. Both are sufficiently common and well-mixed in the atmosphere that they are essentially never limiting (For details see chapter 2, page 17–20). Air as a medium of support is much less buoyant than water. Thus, an organism need relatively little support to survive in water, but it needs a fairly rigid skeleton to live and move on land. Climate in a terrestrial ecosystem is much more variable than it is in water. The most important aspects of climate are the temperature and water relations of ecosystems. These relations include mean annual temperature, amount of temperature fluctuation, annual rainfall, degree and time of fluctuation in rainfall and potential evapotranspiration. Rainfall tends to be somewhat irregular even in the most predictable terrestrial ecosystems, and in arid regions or during periods of drought, lack of water may be a source of extreme stress. The temperature is much more variable on land than in water. This is caused by the fact that aquatic ecosystems are heated by absorption of radiation by water, and water has a high specific heat; terrestrial ecosystems, on the other hand, are heated by the absorption of heat by soil, rock, and vegetation, whose specific heat are much lower. A given quantity of heat energy absorbed by solid material can change its temperature two to five times as much as the same energy absorbed by water. Thus heat is gained and lost rapidly by terrestrial ecosystems, with a resultingly wide fluctuations of temperature, both diurnally and seasonally.

Table : Specific heats of several common substances. (**Clapham, Jr.,** 1973).

1. Fresh water	1·00
2. Sea water	0·93
3. Wet mud	0·60
4. Moist sandy clay	0·33
5. Solid rock	0·20
6. Copper	0·09

In terrestrial ecosystems, the soil serves two major functions—it provide support for living organisms, and it is the source for all essential nutrients except for carbon, oxygen, and hydrogen (For detail see chapter 2, Page 20–37). Even its supportive role is different from the way in which a lake sediment support rooted vegetation. Because the entire weight of all living organisms is borne by the soil, there is no partition of support between the soil and the air. The role of soil as a source of nutrients is unique to trrestrial environments. It is the site of the entire detritus food chain (see chapter 2, Page 38–42) and thus is central to the biogeochemical cycling of nutrient materials. Different types of soils have different properties that affect the availability of nutrients to plants, so the productivity of the terrestrial ecosystems is very closely tied to the chemistry of of the soil. Further, in terrestrial biotic communities interactions between species are real but they are simple, involving relationships like predation, mutualims, parasitism and the like. In contrast to aquatic ecosystems, living organisms of terrestrial ecosystems leave a permanent mark on the system. For example, the role of plants in breaking down and weathering rock and building soil is much more pronounced than it is in almost all aquatic ecosystems. In addition, the succession that takes place in a terrestrial community is almost entirely a function of the organisms within the ecosystem, unlike aquatic successions such as lake eutrophication, which are dependent in large part on materials being washed in from out side.

Lastly, in each of these two ecosystems, namely aquatic and terrestrial ecosystems, several types of major subdivisions can be recognized : thus one can distinguish freshwater, estuarine and marine aquatic ecosystems, and several major types of terrestrial ecosystems such as prairies, forests, tundra, etc. The former are distinguished on the basis of a major chemical difference (*i.e.*, salt content), the latter generally on the basis of the predominant type of vegetation (grass, tree, etc.) (see **Kormondy, 1976**).

CLASSIFICATION OF TERRESTRIAL ECOSYSTEMS

The earth surface—the continental land masses have been classified by biogeographers and ecologists into following regions :

(i) Biogeographic realms.
(ii) Biomes.

(I) BIOGEOGRAPHIC REALMS OR REGIONS

Careful studies of the distribution of plants and animals over the earth have revealed the existence of six major biogeographic realms, namely **Palaearctic realm**, **Nearctic realm**, **Neotropical realm**, **Ethiopian realm**, **Oriental realm** and **Australian realm**, each characterized by the presence of certain unique organisms. Each of these realms embraces a major continental land mass and each remains separated by oceans, mountain ranges, or desert.

(II) BIOMES

Within these biogeographic realms and established by a complex interaction of climate, other physical factors and biotic factors, are large community units called **biomes**. A biome is a large community unit characterized by the kinds of plants and animals present This may be contrasted to the ecosystem, which is a natural unit of living and non-living components that interact to form a stable system in which the exchange of materials follows a circular path. Thus, an ecosystem might be a small pond or a large area coextensive with a biome, but it includes the physical environment as well as populations of animals, plants and micro-organisms.

In each biome the **kind** of climax vegetation is uniform—grasses, conifers, deciduous trees—but the particular **species** of plant may vary in different parts of the biome. The kind of climax vegetation depends upon the physical environment and the two together determine the kind of animals present. The definition of biome includes not only the actual climax community of a region, but also the several intermediate communities that precede the climax community. Further, there is usually no sharp line of demarcation between adjacent biomes ; instead each blends with the next through a fairly broad transition region termed an **ecotone**. There is, for example, an extensive region in Northern Canada where the tundra and coniferous forests blend in the tundra-coniferous ecotone. Some of the biomes recognized by ecologists are **Tundra biome, alpine biome, forest biome, grassland biome, desert biome.**

I. TUNDRA BIOME

Tundra presents the most common example of "fragile ecosystem" (**Clapham, Jr.**, 1973). Tundra which means "marshy plain", lies largely north of latitude 60°N (*i.e.*, between the Arctic ocean and polar ice-caps and the forests to the south) and is characterized by the absence of trees, the presence of dwarfed plants, and an upper ground surface that is wet, spongy and uneven, or hummocky, as a result of freezing and thawing of this poorly drained land (**Kormondy,** 1976). Some five million acres of tundra stretch across Northern America, Northern Europe and Siberia. Although there is variation from place to place within the biome, temperature, precipitation, and evaporation are characteristically low, the warmest months averaging below 10°C and the wettest with about 25mm of precipitation. Despite the small amount of precipitation, water is usually not a limiting factor because the rate of evaporation is also very low.

The ground usually remains frozen except for the uppermost 10 to 20 cm, which thaw during the brief summer seasons. The permanently frozen deeper soil layer is called **permafrost.** The permafrost line which may exist at a depth of a few centimeters to several meters, is the ultimate limit of plant root growth, but the immediate control is the depth to which soil is thawed in summer. The rather thin carpet of vegetation of tundra biome includes few species : grasses and sedges are characteristic of numerous marshes and poorly drained areas, but large areas consist of ericaceous heat plants (bilberries and dwarf huckleberries), low flowering herbs, and lichens. Perhaps the most characteristic arctic tundra plant is the lichen known as "reindeer moss" (*Cladonia*). The animals that have adapted to survive in the tundra are caribou or reindeer, the arctic hare, arctic fox, polar bear, wolves, lemmings, snowy owls, ptarmigans and during the summer, swarms of flies, mosquitoes and a host of migratory birds.

Further, certain animals such as caribou and reindeer are highly migratory because there is not enough vegetation produced in any one local area to support them. Though tundras are barren areas yet a surprisingly large number of organisms have become adapted to survive the cold. During the long daylight hours of the brief summer, the rate of primary production is quite high. The production from the vegetation on the land, from the plants in the many shallow **ponds** that dot the landscape and from the phytoplankton in the adjacent Arctic Ocean provides enough food to support a variety of residant mammals and many kinds of migratory birds and insects. **Diversity** is very low, and despite the extreme hardiness of the tundra organisms, their growth rate tend to be very low, and the community as a structural unit is exceedingly vulnerable

Moreover, Alpine tundra is quite similar to some of Arctic **tundra**, but in the absence of permafrost and in the growing season, **mosses** and lichens are less prominent, flowering plants more so.

2. HIGH ALTITUDE OR THE ALPINE BIOME

The region of mountain above the timber line contains a distinct flora and fauna and is referred as the **alpine zone.** Alpine zone remains conspicuous in those mountains whose peaks reach up to the niveal or snow zone, as in the Himalayas. The alpine zone (zone which lies between timber line and snow zone) includes in the descending order, a **sub-snow zone** immediately below the snow zone, a **meadow zone** in the centre and a **shrub zone** which gradually merges into the timber zone. According to **Mani** (1968) snow zone of Himalayas lies over 5100m above mean sea level and alpine zone exists at a height of 3600m. From an ecological view point, the zone above the limits of tree growth (timber line) exhibits extreme environmental conditions which greatly influence the biota of this region.

The characteristic features of high altitude environment are following—a low air density, low oxygen and carbon dioxide contents and water vapour, high ozone content, high atmospheric transparency affording greater penetration of light, cold, snow cover, increased rate of desiccation, high wind velocity, insolation of high intensity during the day and rapid radiation during the night, the high glare from the sky and snow, high intensity of ionizing radiation and the exclusion of trees. Alpine zone of Himalayas is characterized by a sparseness of animals groups, the scarcity being relatively important as far as tropical Indian, South Chinese, Indo-Chinese and Malayan derivatives are concerned. Important constituents of the fauna of this zone are cold-adapted palaearctic forms (**Mani**, 1968).

Many invertebrates of alpine zone are predatory and occur in lakes, streams and ponds. Among vertebrates fishes and amphibians are totally lacking and reptilian fauna is greatly impoverished.

However, pelobatid frog, *Aleurophryne mammata* is found to occur at 4500 meters of height in Himalayas and viviparous *Mabuya varia* has been reported to live at 4000 meters of height in Mount Kilimanjaro. Some of the representative vertebrates of Himalayan alpine zone are—crow *Corvus corax* ; snow partridge *Lerwa nivicola* ; snow leopard *Felis unica* and *Felis lynx* ; Eropean leech marten *Mustela foina* ; the vole *Lagomys* ; Tibetan yak, *Bos grunnius* ; Tibetan sheep *Ovis hodgsoni* ; pamir sheep *Ovis poli* ; ibex *Capra sibirica*; markhor *Capra falconeri* ; and Persian wild goat *Capra aegagrus*.

A large number of insects and arachnids remain best adapted to Himalayan alpine zone and at 6900 meters height. The torrential streams which are the products of melting snow contain many mayflies, stoneflies and caddisflies. Some of common insects of this zone are—stonefly *Rhabdiopteryx lunata* ; grassophers like *Bryodema* and *Gomphomastax* ; apterous species *Conophyma* ; *Dicranophyma* ; *Spingonotus* ; tettigonid *Hypsinomus fasciata* ; earwigs like *Anechura* ; bugs like *Dolmacoris*, *Tibetocoris*, and *Nysius ericae* ; aquatic beetle *Amphizoa* ; carabids like *Bembidion*, *Carabus Calosoma*, *Harpalus*, *Trechus*, *Calathus*, *Bradytus*, *Broscus*, and *Dyschirius* ; staphylinids like *Atheta*, *Aleochara*, *Geodromicus*, *Oxypoda*, *Philonthus* and *Tachinus* ; tenebrionids like *Bioramix* and *Chianalus* ; ants like *Formica picea* ; bumble bees like *Lapidariobombus separandus* ; butterflies like *Colias*, *Argynnis* and *Parnassius* ; the fly *Deuterophlebia* ; collembolans like *Entomobrya*, *Isotoma*, *Proistoma*, *Hypogastrura*, *Isotomurus*, *Tomocerus* and *Onychiurus* ; and numerous simulids blepharocerids, syrphids, anthomyids tachinids and sarcophagids, (**Ananthakrishnan** and **Visvanathan**, 1976).

3. FOREST BIOMES

The word **forest** is derived from Latin '*foris*' meaning outside, the reference being to village boundary or fence, and must have included all uncultivated and unihabited land. Today a forest is any land managed for the diverse purposes of forestry whether covered with trees ,shrubs, climbers, etc., or not (see **S.P. Sagreiya**, 1967). The forest biomes include a complex assemblage of different kinds of biotic communities. Optimum conditions of temperature and ground moisture responsible for the growth of trees contribute greatly to the establishment of forest communities. In addition, 50 mm rainfall is a pre-requisite for the growth of trees. The nature of soil, wind and air currents determines the distribution (abundance or sparseness) of forest vegetation. Normally ecologists recognise among forest communities such features as their evergreen nature, whether deciduous or indeciduous, as well as their shape, whether broad- leaved as in temperate forests or more needle-like as in the conifers. On the basis of these features the forest biomes of the world have been classified into following biomes—**coniferous forest, tropical forest**, and **temperate forest**. All these forest biomes are generally arranged on a gradient from north to south or from high altitude to lower altitude.

(i) Coniferous forest : Cold regions with high rainfall and strongly seasonal climates with long winters and fairly short summers are characterized by boreal conifer forest which is transcontinental. For example, adjacent to the tundra region either at latitude or high altitude is the **northern coniferous forest**, which stretches across both North America and Eurasia just south of the tundra (*i.e.*, Canada, Sweden, Finland, Siberia and Mussoorie). The term **Taiga** is applied to the northern range of coniferous forests. This is characterized by evergreen plant species such as spruce (*Picea*, etc.), spruce (*Picea, glauca*), fir (*Abies balsamea*) and pine trees (*Pinus resinosa, Pinus strobus*) and by animals such as snow shoe hare, the lynx, the wolf, bears, red fox, porcupines, squirrels, amphibians like *Hyla* and *Rana*, etc. Large size is common, both in the trees, which range up to some 40 m in height, and in vertebrates, which include the giants of several groups of animals, such as moose, caribou, elk, grizzly bear, wolverine, beaver, and several large species of birds. Species diversity is low, and pure stands of trees and shrubs are common, as are outbreaks of defoliating insects of several sorts (*e.g.*, bark beetles, saw flies, geometrid moths, etc.). Understory trees are uncommon as a result of the continual low light penetration. Among common understory associates are orchids and ericaceous shrubs like the blue berry. The thalloid mosses and lichens being very rich understory vegetation.

Boreal forest soils are thin podozols, and are rather poor both because the weathering of rock proceeds slowly in the cold environments, and because the litter derived from conifer needle is broken down very slowly and is not particulary rich in nutrients. These soils are acidic and mineral deficient, the result of the movement of a large amount of water through the soil; in the absence of a significant counter upward movement of evaporation, soluble essential nutrients like calcium, nitrogen, and potassium are leached sometimes beyond the reach of roots thereby leaving no alkaline-oriented cations to encounter the organic acids of the accumulating litter (**Kormondy, 1976**). The productivity and community stability of a boreal conferous forest are lower than those of any other biome.

(ii) Temperate deciduous forest : The temperate forest biomes are characterized by a moderate climate and broad-leaved deciduous trees, which shed their leaves in fall, are bare over winter and grow new foliage in the spring. These forests are the characteristics of north America, Europe, Eastern Asia, Chile, part of Australia and Japan, with a cold winter and a annual rainfall of 75—150 cm and a temperature of 10—20°C. In these biomes the precipitation may be fairly uniform throughout the year. In India, at elevations of 9000—12,000′ in Himalayas occur temperate vegetation including pines, fir, yew and juniper trees with an undergrowth of scrubby rhododendrons.

Soils of temperate forests are podozolic and fairly deep. Trees are quite tall—about 40—50m in height—and their leaves are thin and broad. The predominant genera of this biome are maple (*Acer*), beech (*Fagus)*, oak *(Quercus)*, hickory (*Carya*), basswood *(Tilia)*, Chestnut *(Castnea)*, cottonwood *(Populas)*, sycamore *(Platanus)*, elm *(Ulmus)*and willow *(Salix)*. In some locations, coniferous vegetation may be quite predominant and that includes white pine (*Pinus strubos)*, hemlock *(Tsuga canadensis)* and red cedar *(Juniperus virginianus*). There are not many epiphytes or lianas save for some species of mosses, algae and lichens growing on tree trunks,and a few vines, notably *Vitis*, the grape. The understory of shrubs and herbs in the deciduous forest is typically well-developed and richly diversified, with a coniderable portion of the photosynthesis and flowering attuned to the short days of the spring season, prior to the leafing out of and consequent shading by the tree canopy. Accordingly, there are often two separate herb assemblages. One consists of spring flowers, which bloom before the trees have expanded their leaves and are gone by summer, and the other is adapted to the low light levels of the forest floor and lasts into the fall.

The animals orginally present in temprate forests were deer, bears, squirrels, gray foxes, bobcats, wild turkey and wood peckers. Other common animals of this region are invertebrates like earthworms, snails, millipedes, Coleoptera and Orthoptera and vertebrates like amphibians such as newts, salamanders, toads, and cricket frogs; reptiles such as turtles, lizards and snakes ; mammals such as racoon opossum, pigs, mountain lion, etc., and birds like horned owl, hawks, etc. All these animals and plants show a profound seasonality; some may even hibernate throughout the winter. The range of animal size and adaptations is wide ; the largest animals include such forms as the deer and black bear. The dominant carnivores are large, including the wolf and mountain lion, although smaller carnivores such as fox and skunk are also common. Diversity of fauna is lower than in any of the rain forests and a few species seems clearly to be dominant.

(iii) Temperate evergreen woodland : Many parts of the world have a Mediterranean-type climate with warm, dry summers and cool, moist winters. These are commonly inhabited by low evergreen trees with small hard needles or slightly broader leaves. The most important area of tropical evergreen woodland in North America is the **'Chaparral'** of the Pacific Coast, the Mediterranean **'maquis'**, Spanish **'encinar'** and **'melle scrab'** on Australia's South Coast are the same type of community. In such a woodland, trees are essentially lacking, although shrubs may range up to 3—4 m in height. Species diversity is roughly intermediate between that of a temperate deciduous forest and a drier grassland. Fire is an important factor in this ecosystem, and the adaptations of the plants enable them to regenerate quickly after being burned. The characreristic animals of temperate evergreen woodland or chaparral are mule deer, brush rabbits, wood rats, chipmunks, lizards, wem-tits and brown towhees. Small-hooved cursorial ungulates are the dominant herbivores. Saltatorial (jumping) animals and many fast moving ungulates are also common in this fauna.

(iv) Temperate rainforests : The temperate rainforest is a colder ecosystem than any other rainforest. Such a forest has a definite seasonality, with both temperatures and rainfall varying throughout the year. Rainfall is high, but fog may be very heavy and actually more important as a source of water than rainfall. The diversity is much lower, both in plants and animals, in comparison to warmer rainforests, yet it remain still higher than other temperate forest types. The dominant trees (canopies) are coast redwood (*Sequoia sempervirens*) of the Pacific coast of North America and the alpine ash (*Eucalyptus regnans*) of Australia and Tasmania, both of which reach more than 100 m in height Epiphytes and lianas are common but are not abundant like those of other rainforests. The animals of temperate rainforests are similar to those of deciduous forests, but show a somewhat higher diversity.

(v) Tropical rainforests : Tropical rainforests occur near the equator in Central and South America, Central and Western Africa (Congo, Zambesi river), Southeast Asia (parts of India and Malaysia), Malaya, Borneo, New Guinea and Northwest Australia. Tropical rainforests are among the most diverse communities on earth. Both temperature and humidity are high and constant. The annual rainfall which exceeds 200 to 225 cm is generally evenly distributed throughout the year.

The flora is highly diversified : a square mile may contain 300 different species of trees, a diversity unparalleled in any other biome. The extremely dense vegetation of the tropical rainforests remain vertically stratified with tall trees often covered with vines, creepers, lianas, epiphytic orchids and bromeliads. Under the tall trees is a continuous evergreen carpet, the canopy layer, some 25 to 35 meters tall. The lowest layer is an understory of trees, shrubs, herbs like ferns and palms, all of which become dense where there is a break in the canopy. Nearly all plants are evergreen, and those that do lose their leaves entirely do so at irregular intervals with no apparent regard to the climatic regime. The leaves of most plant are of moderate size, leathery and dark green in colour. Their roots are often shallow and have swollen bases or flying buttresses.

Soils of tropical rainforests are red latosols, and they may be exceedingly thick. The high rate of leaching makes these soils virtually useless for agriculture purposes, but if they are left undisturbed the extremely rapid cycling of nutrients within the litter layer (due to decomposition) can compensate for the natural poverty of the soil. It is the nature of the soil, both its potential for high leaching as well as its chemical composition that promotes a rock-like quality when exposed to air, that largely has prevented western style agriculture from being applied to the tropical forests (**Kormondy**, 1976).

Invertebrate density and abundance are very high in tropical rainforests, but while vertebrates are diverse, they are not as abundant as in many other communities. The common invertebrates of these forests are worms, snails, millipedes, centipedes, scorpions, isopods, spiders, insects, planarians and leeches. Among insects, heteropterans, orthopterans, blattids, mantids, phasmids, bees, termites and ants are most common. The common vertebrates of tropical rainforests are the arboreal amphibian *Rhacophorus malabaricus*; aquatic reptiles, chameleons, agamids, geckoes, and many species of snakes; many species of birds, social birds being predominant; and a variety of mammals. Nocturnal and arboreal habits are most common in many mammals such as insectivores, leopards, jungle cats, ant-eaters, giant flying squirrels, monkeys and sloths. But in New Guinea and Northern Queensland, where monkeys are absent, there are arboreal kangaroos (***Dendrolagus*** **sp.**), despite the fact that the basic anatomy of the kangaroo is not particularly well-suited to arboreal life. Further, in the foot hills of the forest zone of peninsular India covered with dense tropical vegetation, we have the tiger (*Panthera tigris*), the elephant (***Elephas*** *maximus*), samber deer (*Rusa unicolor*), muntjac (***Muntiacus muntjak***), the gaur (*Bibos gaurus*), the chital or spotted deer (*Axis axis*), and the swamp deer (*Rucervus duraucelli*) as the major ground dwelling mammals (see **Ananthakrishnan** and **Viswanathan**, 1976).

(vi) Tropical seasonal forests : Tropical seasonal forests occur in regions whose total annual rainfall is very high, but segregated into pronounced wet and dry periods. Tropical seasonal forests are found in Southeast Asia, Central and South America, Northern Australia, Western Africa and the tropical islands of the pacific as well as India and Southeast Asia. In exceedingly wet tropical seasonal forests, commonly known as **monsoon forests**, the annual precipitation may be several times that of the tropical rainforest. Trees may reach heights over 40m, but are more commonly 20–30m high. Stratification is of a relatively simple type with a single understory tree layer, canopy is deciduous and understory is evergreen. Teak is often a major large tree in the best-known tropical seasonal forests, those of India (Central India) and Southeast Asia. Bamboo is also an important climax shrub in these areas, although in other areas it is important only in earlier stages of the succession.

(vii) Subtropical rainforests : In regions of fairly high rainfall but where temperature differences between winter and summer are less marked, as in Florida(USA), the broad-leaved evergreen subtropical biome is found. The vegetation includes mahogany, gumbo limbo, bays, palms, oaks, magnolias, tamarinds, all laden with epiphytes (of pineapple and orchid families), ferns, vines and strangler fig (*Ficus aureus*). This, stratification is simpler, with only one understory tree horizon. All these plants tend to be evergreen, but may lose their leaves during the dry season. Animal life of subtropical forest is very similar to that of tropical rainforests.

4. TROPICAL SAVANNA BIOMES

Savannas are tropical grasslands with scattered, drought-resistant trees which generally do not exceed about ten meters in height and do not forming a canopy. Thus, a savanna is an intermediate between a forest and a grassland. Savannas constitute extensive areas in Eastern Africa, which support the richest diversity of grazing mammals in the world, and also occur in Australia, South America and Asia. The climate is generally characterized by a rainy (May through October) and dry (November through April) season ; in the llanos of Venezuela, for example, nearly 90 per cent of the annual rainfall of 130 cm falls during the rainy season. The latosol soils of savannas are nutrient poor owing a heavy leaching, quite widely distributed in savannas are soils called laterite which when dried harden to rock-like consistency thereby precluding their use in westeamstyle agriculture (**Kormondy**, 1976). Although climate and soil are significant regulating factors in this biome, the controlling factor appears to be fire, which gives grasses and certain species of trees a powerful advantage over other tree species. As a result of this latter factor, species diversity is quite low in comparison to adjacent tropical forests ; in some situations a single species of both grass and tree may be dominant over large areas.

The trees of savannas are resistant to desiccation, and may be either deciduous or evergreen. Their leaves are often hard and drought-resistant. Grasses are the most conspicuous plants, and may reach heights of 1½—2 m. Gigantism of certain animal groups in these tropical savannas is as pronounced as it is in the boreal forest including such giants as many antelopes, giraffes, elephants, buffalo and lions (**Clapham Jr.**, 1973). In addition, a rich insectan fauna especially those with strong mandibles capables of mastication are conspicuous in this biome. Grasshoppers and termites are encountered in large numbers.

5. GRASSLAND BIOMES

The grassland biome is found where rainfall is about 25 to 75 cm per year, not enough to support a forest, yet more than of a true desert. The seasonality of grasslands is pronounced, both with respect to rainfall, which is concentrated in the summer and to temperature. Grasslands typically occur in the interiors of continents and include the **tall grass prairies, short** grass **prairie** or great plains and **arid grassland** of North America as well as the **steppes** of Eurasia (Southern Russia, Siberia and Asia), the **veldt** of Africa and the **pampas** of South America (Argentina). The grassland communities are open land communities with limited moisture conditions, irregular rainfall, sharp seasonal and diurnal variations and very high radiation. Since tall trees or other thick vegetations are excluded from these communities there is a free movement of air. These winds carry the particles of sand or dust. These open habitats provide natural pasture for grazing animals (herbivore) which are excluded from predation by predators which hide in thick vegetation and prey upon them.

In grasslands, the stratification is reduced essentially to a single story, but within that level, species diversity may be as high as in a deciduous forest-especially for the tall grass prairies. Only along the streams are trees to be found, but the "gallery forests" within a few meters of stream bank are is characteristic of grasslands. The grasses comprising the grasslands can be divided into two basic groups, the tall grasses more than 1 m high, which are found in moist portions of the grassland, and the short grasses less than 1 m high, which are found in the drier regions. For example, prior to its conversion to agriculture and urban development, the tall grass prairie toward east of North America was dominated by species of bluestern (*Andropogon*) forming dense covers four to six feet tall. Westward, Buffalo grass (*Buchloe dactyloides*) and other grasses but a few centimeters high dominated the landscape. Flowering herbs including many kinds of composites are common, but much less important than grasses.

Since the precipitation—evaporation ratio is below 1 in the grassland, leaching is considerably less. The soils of the grasslands are rich, fertile prairie soils (black-earths) and chernozems. Organic matter (humus) accumulates in the upper portion of the soil, rendering it dark ; this upper portion remains neutral to slightly alkaline because of the continued replenishment of cations like calcium and potassium through the upward movement associated with evaporation.

Typical animals of grasslands tend to be quite small, with the exception of a few very large cursorial herbivore mammals such as the bison and pronghorn in North America, the wild horse, ass, and saiga antelope of Eurasia and zebra and antelopes of Southern Africa. The large herbivores are no where near as diverse as they in savanna areas. Likewise, carnivores are relatively small, such as coyotes, weasels, badgers, foxes, ferrets, owls and rattle snakes. Rodents such as prairie dogs, rabbits, and ground squirrels are common. Most herbivores characteristically aggregate into herds or colonies ; this aggregation provide some protection against predators. The characteristic birds of grasslands are prairie chickens, meadow larks, and rodent hawks. Further, saltatorial motion is widespread, not only in mammals such as rabbits and kangaroo rats, but also in insects, such as grasshoppers and crickets. This probably has to do with increasing rate at which animal can move through or over the tall grasses, as well as making it harder for a predator to catch the animal. Visibility in the grasslands is exceedingly good and the premium placed on efficiency including predators is very high.

The common insects of steppes are termites, locusts (*Locusta migratoria, Schistocerca gregaria* and *Melanoplus* sp.) bees, burrowing wasps mutilid wasps, bumble bees and blister bees. The steppes also harbour an undisturbed reptilian fauna. Lizards and snakes are met with in large numbers and possess remarkable diversity. Most of them are fossorial, insectivorous and carnivorous.

6. DESERT BIOMES

Deserts are the biome formed in the driest of environments, Temperature may range from very hot as in **hot deserts** to very cold as in **cold deserts**. Major hot deserts of the world are situated near the tropics of cancer and capricon, with a rainfall of less than 10 mm. The most important hot deserts of world is the Sahara-Arabia-Gobi desert complex extending from Africa to Central Asia and contains highly irregular and very insignificant rainfall, and low humidity due to excessive evaporation. Fairly extensive hot deserts also occur in India (Sind-Rajasthan deserts), South America (Chile), North America and Australia. The cold deserts occur at high elevations where the temperatures are low and rainfall scanty as the air losses all its moisture content as it ascends higher and higher. Cold deserts occur in Ladakh regions of Himalayas, Tibet, and Bolivia Arctic. The hot and cold deserts may also be distinguished by differences in plant population which are mostly succulent type (e.g., cactus, palo verde trees, creosote bush, etc.). Most cold deserts have sage brush.

Low erratic precipitation coupled with soil and air temperatures that are extremely high by day and drop abruptly by night, low humidity, and high insolation are the major desiccating environmental factors to which desert vegetation and animals have adapted. Desert plants which tend to be shrubs are adapted to drought conditions through reduced leaf size and the dropping of leaves in dry conditions, both reducing water loss via evapotranspiration. The roots of most desert plants remain well developed and occur in the top meter of the soil to take maximum possible advantage of any rainfall. Further, the root hairs on many desert plants are ephemeral, drying back under drought conditions and thereby reducing potential water loss by osmosis. Yet other species are short lived annuals that complete their life cycles during the short-moist period. In most hot deserts, there occur plants such as cacti, water-storing succulents such as acacias, euphorbias, cacti, prickly pears, etc., which are adapted by their protoplasmic colloids, which enable the accumulation of substantial water reserves, as well as by a reduced leaf sur face, which obviates water loss via evapotranspiration.

The animals present in the desert are reptiles, insects and burrowing rodents. All these animals possess special morphological, physiological and ethological adaptations for deserts. In general, large animals are very uncommon except mule deer and some species of gazelle and all animals have cursorial, fossorial and/or saltatorial adaptations. Some desert animals are nicely adapted for high extremes of temperature. For example, the lethal temperature of different species of insects found to be following—for the camel spider *Galeodes granti* it is 50°C, for the *Gryllus domesticus* it is 40°C and for the forficulid *Labidura riparia* it is 38°C (**Cloudsley—Thompson,** 1962). Diurnal rhythms are perhaps the best method of avoiding the heat. While some desert plants close their petals at night, many blossom only at night. Some insects like tenebrionid beetle *Akis spinosa* remain active during the day, and the centipede *Scolopendra clavipes* restricts its activities to night time.

Further, certain reptiles and certain insects are well adapted for survival in deserts because of their thick, impervious integuments and the fact they excrete dry waste matter. A few species of mammals have become secondarily adapted to the desert by excreting very concentrated urine. They avoid the sun by remaining in their burrows during the day. Kangaroo rat and pocket mouse, both are able to live without drinking water by extracting the moisture from the seeds and succulent cactus they eat. The camel and the desert birds (Ostrich, etc.) must have an occasional drink of water but can go for long periods of time using the water stored in the body. Most insects of deserts are herbivores and as a correlation the number of small insectivorous lizards found in the desert is usually high.

Fauna of Indian deserts : Prakash (1974) have recognized four habitat types in the Indian desert based on land forms namely **aquatic, sandy** and **rocky ruderal habitats**. The aquatic habitat of Indian deserts which remains confined to the perennial lakes, are inhabited by various species of fishes like *Labeo nigripinnis, Oxygaster clupeoides, Tor khurdee, Puntius amphibia, Noemacheilus denisonii.* Among amphibians of the Indian desert are a species of toad (*Bufo andersonii*) and five species of frogs (Indian bull frog *Ramna tigrina*, cricket frog *Rana limnocharis* and burrowing frog *Rana breviceps* being dominant species). Among reptiles, there occur two species of testudines (Loricata), 18 species of lizards and 18 species of snakes. Of the lizards, some species like *Acanthodactylus cantoris, Calotes versicolor, Uromastix hardwicki, Ophiomorus tridactylus* are predatory on the desert locust inhabiting localized areas in the Thar desert. The avian fauna of the Indian desert includes species like painted partridge *Francolinus pictus pallidus*, grey partridge *Francolinus pondiceriamus*, common quail *Coturnix coturnix*, black breasted quail *Coturnix coromandelicus*, rock bush quail, the little bustard quail *Lurnix sylvatica*, button quail *Turnix tanki*, great Indian bustard *Choriotes nigriceps*, florican *Sypheotides indica*, sandgrouses like *Petrocles exustus erlangeri*, *Petrocles alchata*, *P. senegallus*, and *P. indicus indicus*. During winter numerous aquatic birds become abundant in Indian deserts. Such birds are white fronted goose *Anser albifrons*, wigeon *Anas penelope*, garganey *Anas querguedrila*, red crested pochard *Netta fufina* and tufted duck *Aythya futigola*. Among the predominant predatory birds are two species of the vultures namely *Gyps bengalensis* and the white vulture *Neophron percnopterus*.

The mammalian fauna of Indian deserts includes many species, some of which have been tabulated in following table :

Table : Certain common mammals of Indian deserts (**Prakash,** 1974).

Order	Species	Popular Name
1. **Chiroptera**	*Rosetius arabicus*	Fruit bat
	Pteropus giganteus giganteus	Fruit bat
	Rhinopoma kinneari	Rat-tailed bat
	Rhinopoma hardwicki	The lesser rat-tailed bat
	Taphozour perforatus	Tomb bat.
	Megaderma lyra	Indian false vampire
	Rhinolophus lepidus lepidus	Horse-shoe-bat
2. **Insectivora**	*Hemiechinus auritus collaris*	Long ear hedgehog
	Paraechinus micropus	Long-ear hedgehog
	Suncus muinus sindensis	House Shrew
3. **Pholidota**	*Manus crassicaudata*	Scaly ant eater
4. **Lagomorpha**	*Lepus nigricollis caudatus*	Hare
	Lepus nigricollis dayanus	Hare
5. **Rodentia**	*Funambulus pennanti*	Northern palm squirrel
	Hystrix indica indica	Indian crested porcupine
	Rattus rattus	House rat
	Mus musculus rufescens	House mouse
	M. musculus bactrianis	House mouse
	Gerbillus gleadovi	Indian hairy footed gerbil
	Tatera indica	Gerbil
	Merriones hurrianae	Gerbil
6. **Artiodactyla**	*Sus scrofa cristata*	Wild boar
	Boselaphus tragocamelus	Blue bull
	Antilope cervicapra rajputani	Black back
	Gazella gazella bennetti	Gazelle
7. **Carnivora**	*Canis lupus*	Wolf
	Canis aureus	Asiatic jackal
	Vulpes vulpes	Red fox

Order	Species	Popular Name
	Vulpes bengalensis	Bengal fox
	Lutra perspicillata	Indian otter
	Viverricula indica	Small Indian Civet
	Herpestes auropunctatus	Small Indian mongoose
	Felis chaus prateri	Jungle cats
	Felis libyes ornata	Jungle cats
	Panthera pardus sindica	Panther

All these mammals have well specialized adaptations for survival in thermal extremes and low humidity. Many of them possess diurnal rhythmic activities.

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